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Research Paper **NC-211**

A New Machine for Producing Chunkwood

Rodger A. Arola, Robert C. Radcliffe, Sharon A. Winsauer, and Edsel D. Matson

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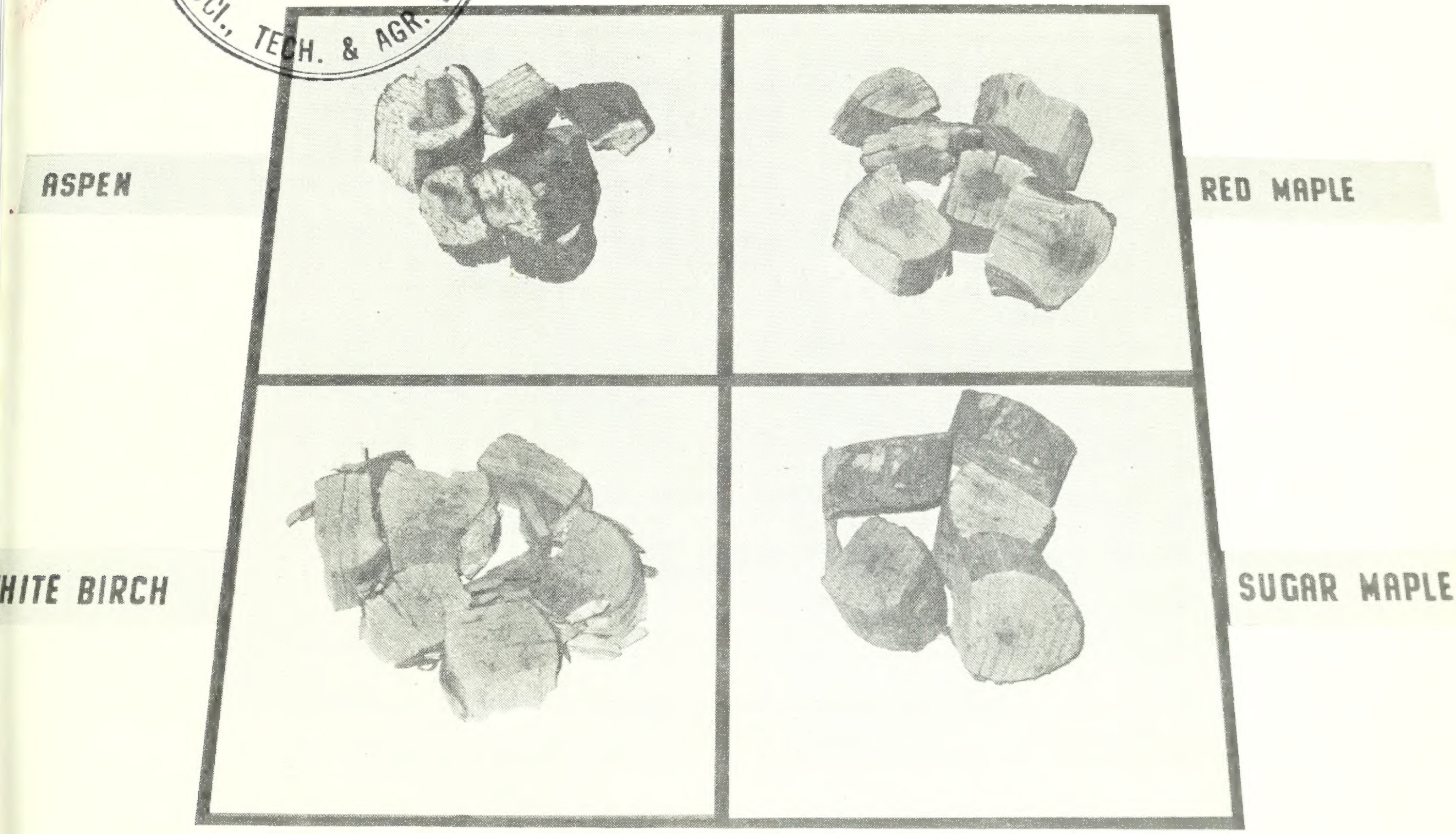

North Central Forest Experiment Station
Forest Service — U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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1982

A NEW MACHINE FOR PRODUCING CHUNKWOOD

Rodger A. Arola, *Principal Mechanical Engineer,*
Robert C. Radcliffe, *Mechanical Engineering Technician,*
Sharon A. Winsauer, *Computer Specialist,*
and **Edsel D. Matson,** *Mechanical Engineer,*
Houghton, Michigan

As fossil fuel resources are depleted and prices escalate, there are increasing pressures for alternate industrial fuels. Wood is one alternative, particularly for industries located in heavily forested areas. However, a way is needed to reduce small trees and forest residue into a convenient form for direct combustion as a primary or supplementary fuel or as a wood gasifier feedstock.

Chips produced with conventional whole-tree chippers are small and not ideally suited for solid fuel combustors even though such chips are currently being used. Wood and coal, both solid fuels, generally require large combustion chambers. When wood is used to supplement coal, the typical pulp-size chips burn faster than stoker-sized coal, so the wood is burned off first. To obtain nearly equal combustion time for wood and coal, a larger wood particle is needed. Also, when pulp-size chips are burned in large industrial units, high stack gas velocities carry small particles and fly ash up the stack as solid particulates. Larger wood chunks would eliminate this problem — chunks ranging in size from a cigarette package up to 2- to 4-inch long discs from small diameter wood.

Also, the flakeboard industry would benefit from the longer fibers that the larger particles would yield. The Forest Products Laboratory in Madison, Wisconsin (Erickson 1976), recommended the development of a "fingerling" particle 2-1/2 to 3 inches long with a preferred cross sectional area of less than 1 square inch that could be ring flaked to yield the length properties desired for manufacturing exterior grade structural flakeboard. The chunks derived from this device can easily be further reduced in size to permit ring flaking.

Responding to this need we have developed two prototype devices to produce chunky wood particles to specified length. The largest chunks or discs produced by these machines are equal to the bolt diameter and about 2 inches long, with much fracturing along the grain. The chunks produced with either device can be readily used as energy wood or as a preferred intermediate form for manufacturing structural flakeboard. The first invention, a helical or spiral head chipper, has been described (Barwise *et al.* 1977, Erickson 1976). The latter is an involuted disc chunker (Barwise *et al.* 1982). This chunker and the results of initial prototype testing are described here (fig. 1).

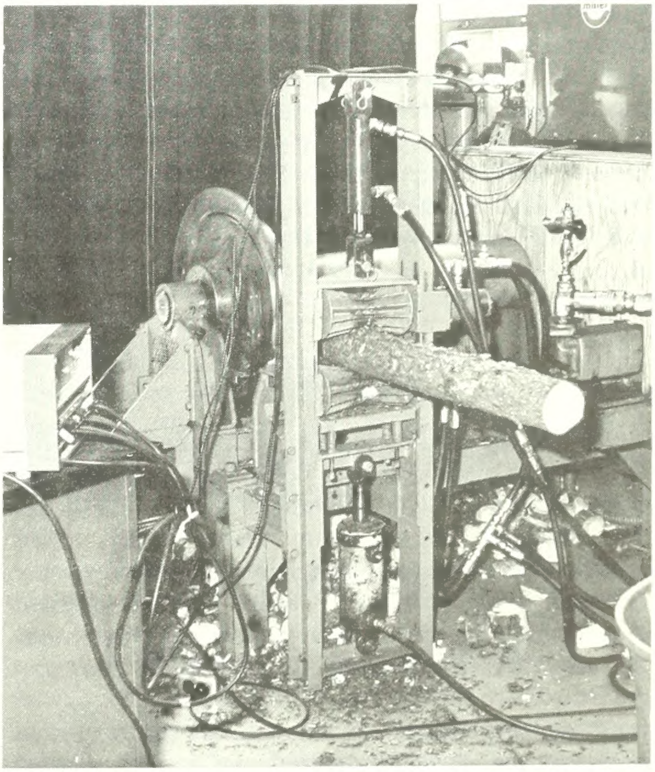

Figure 1. — *Experimental involuted disc chunker.*

THE STUDY

Machine Description

The experimental involuted disc chunker consists of a 24-inch-diameter disc mounted on a horizontal shaft supported by a pair of bearings secured to a rigid frame (fig. 2). A pair of blades 18 inches long, bent to a 12-inch radius, was mounted 180° apart at right angles to one face of the disc. The blades were mounted on the disc with the trailing end spiraling inward, i.e., involuted. The blades were tapered so that the leading cutting edge would project out 1/2-inch from the disc face and the trailing edge 5 inches, which is equivalent to maximum depth of the cut. The blades were sharpened to a 30-degree double bevel and were 1/4-inch thick.

An "anvil" was fabricated from a short piece of 6-inch diameter pipe and secured horizontally to the infeed frame so that the center of this pipe was 2 inches below the center of the disc. The inner end of the anvil was contoured to provide clearance for the rotating blade assembly.

The disc is driven by a hydraulic motor through a roller chain drive. The hydraulic motor, in turn, is operated by a hydraulic pump unit run by a 25 hp electric motor. Disc speeds were varied from 50 to 504 rpm by using different size sprockets.

A pair of hydraulically operated and spring-loaded feed rolls was mounted just ahead of the anvil to provide a firm yet flexible feed control over the log being chunked. These rolls were powered and positioned by a second hydraulic unit. The feed rolls were adjusted during the tests so that the workpiece was fed 15 to 20 percent faster than the theoretical feed rate to insure the bolt end met the feed stop for each cut, thereby producing uniform segment lengths.

Procedure

Because the experimental machine was developed to chunk only small diameter bolts, test bolts were obtained from trees with a diameter of 1.5 to 4.5 inches. The species tested were sugar maple *(Acer saccharum)*, red maple *(Acer rubrum)*, quaking aspen *(Populus tremuloides)*, white birch *(Betula papyrifera)*, American basswood *(Tilia americana)*, and jack pine *(Pinus banksiana)*. Selected trees were cut into two to three 8-foot bolts and coded. Discs were removed from the ends of each bolt of freshly cut wood to determine moisture content and specific gravity. Moisture content was determined on a green-weight basis, specific gravity and density by dry weight-green volume as specified by TAPPI Standard T 18 m-53 (TAPPI 1967). Chipping tests were conducted on both frozen and as-cut/unfrozen wood. Bolts chipped frozen were stored in a freezer for about 2 months below 0°C.

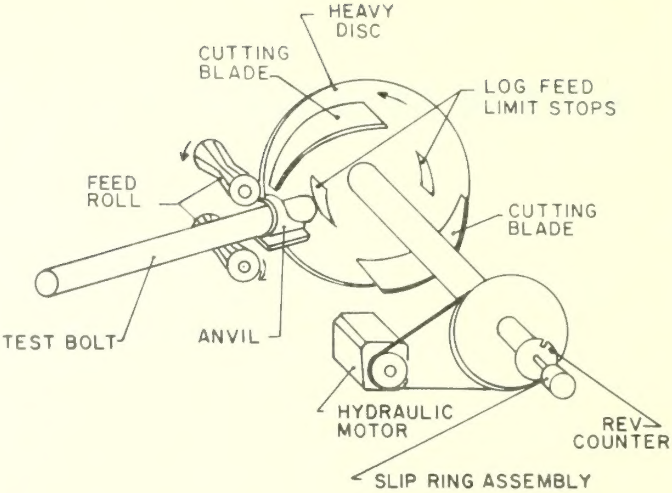

Figure 2. — *Simplified illustration of experimental involuted disc chunker.*

To eliminate possible effects of end drying between time of cut and test, a 1-foot piece was cut from each end of the bolt immediately before chunking, leaving a 6-foot long test bolt.

The length, weight, species, and both end diameters of the test bolts were recorded. The large end of the test bolt was placed into the tubular anvil and the feed rollers positioned. With the cutting disc rotating at the desired test speed, the feed rolls and the recording instrumentation were activated simultaneously. Thus torque, torque integrated over time, and rpm were recorded on an oscillograph.

After completing the tests for a given species, the resulting chunks were put into a calibrated container to determine bulk density of the particles.

A sample of the chunkwood produced from each specie was later fed through a hammermill with the bar grate removed, to break the disc-sized chunks into smaller pieces similar to the "fingerling" particles described earlier. The resulting particles were classified by size.

Some of the larger test samples would not chunk because of insufficient power. To increase the power, the hydraulic power package was modified to increase the flow of oil to the hydraulic motor driving the cutting disc. This increased the disc rpm and available torque for a given sprocket size.

This modification worked as shown by the tests on sugar maple at 92 vs 105 rpm. At 92 rpm, only 47 percent of the bolts could be chunked with an average diameter of 2.3 inches. After the flow modification (105 rpm), 86 percent of the bolts were chunked, with an average diameter of 3.1 inches. Torque, horsepower, and energy used were recorded for all test bolts that were chunked.

Instrumentation

Four 350 ohm strain gages were arranged on the chipper shaft in a Wheatstone Bridge configuration and amplified so that a torque signal of appropriate amplitude was produced (fig. 3). This torque signal was simultaneously integrated and amplified within the system and recorded along with instantaneous torque and rpm on a recording oscillograph. To measure rpm, a photosensitive device was attached to the disc shaft, which produced a pulse with each revolution.

To initially calibrate the strain-gaged shaft and recording instruments, a known physical load was applied to the disc shaft while in a locked condition. No-load disc speed was determined by using a tachometer.

Data Analysis

Chunking production rate, average torque, average horsepower, and energy consumption were calculated from the descriptive data and the integrated torque curve by the following equations:

$$\text{Production rate (ft}^3\text{/min)} = \frac{\text{Volume chipped}}{\text{Time}}$$

$$\text{Average torque (ft-lb)} = \frac{\text{Calibration constant x integrated torque deflection}}{\text{Time}}$$

$$\text{Average horsepower (hp)} = \frac{\text{Average torque x rpm}[1]}{5252}$$

$$\text{Energy}\left(\frac{\text{hp-min}}{\text{ft}^3}\right) = \frac{\text{Average hp}}{\text{Production rate}}$$

$$\text{Energy}\left(\frac{\text{hp-hr}}{\text{O.D. Ton}}\right) = \frac{33.33}{\text{Dry density}} \text{ x Energy}\left(\frac{\text{hp-min}}{\text{ft}^3}\right)$$

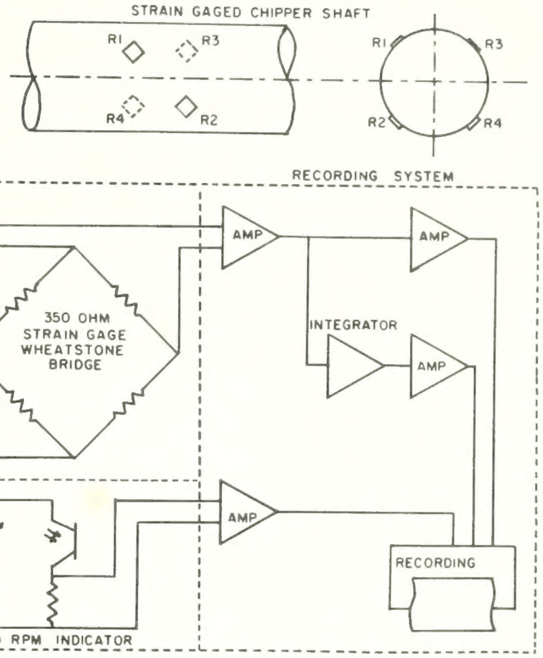

Figure 3. — *Schematic of instrumentation system.*

Scatter plots and analysis of the data were made to identify significant relationships. Originally, only four disc speeds ranging from 50 to 225 rpm were scheduled to be tested. When it was later determined that the machine could be modified to run at speeds up to 500 rpm, two additional series of tests were scheduled for birch and red maple.

A theoretical production rate was determined from the volume removed per cut, the number of cuts per revolution, and the rpm. Assuming a 2-1/2 inch nominal segment length removed per cut, the theoretical production rate in cubic feet per minute = 0.0023 rpm x $(\text{DIA})^2$. A linear regression was used to obtain the actual production rate from timing data for all species combined. This yielded an r^2 value of 0.97. Actual production rate (cu ft/min) = 0.0018 rpm x $(\text{DIA})^2$ The actual production rate was 20 percent lower than theoretical (fig. 4) primarily because of a decrease in disc rpm during chunking versus a theoretical calculation based on no-load rpm.

THE RESULTS

Power Requirements

The average torque was influenced by species, rpm, bolt diameter, and whether the wood was frozen or unfrozen (fig. 5). Limited data for red maple and

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[1] *No load rpm.*

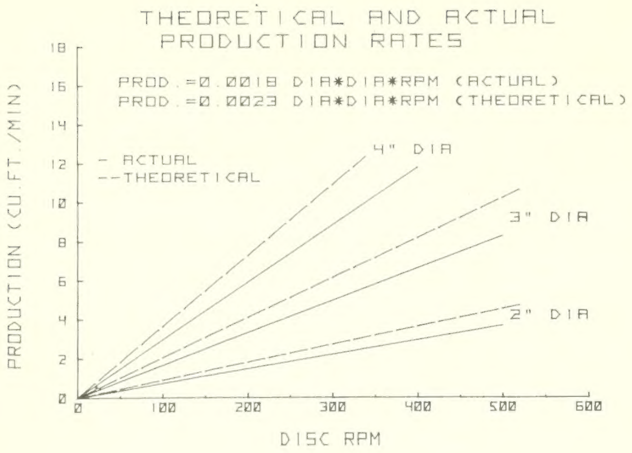

Figure 4. — *Comparison of chipping rates with 2- to 4-inch-diameter logs.*

white birch suggest that a large decrease in the average torque occurred between 225 and 336 rpm. Benefits derived from the higher rpm and flywheel energy should be investigated further, because low torque values result in lower horsepower and energy requirements.

Within the rpm range tested, twice as much energy was required to chunk sugar maple as the less dense aspen and basswood. For a given species, a major factor affecting energy requirements is rpm. For example, the average energy required to chunk red maple was 4.8 (hp-min/cu ft) in the range of 92 to 152 rpm but dropped to 1.5 (hp-min/cu ft) at 339 rpm.

The large diameter bolts required greater torque and energy to cut. However, because the production rate also increases with increasing bolt diameter, the incremental change in energy was proportionately less than the increase in torque. To illustrate, for sugar maple at 105 rpm, torque rose from 525 ft-lb for bolts 2.5 to 3.5 inches diameter to 943 ft-lb for those more than 3.5 inches — an increase of 80 percent. However, because there was a corresponding increase of 70 percent in the chunking production rate, the increase in required energy was only 10 percent — from 6.1 to

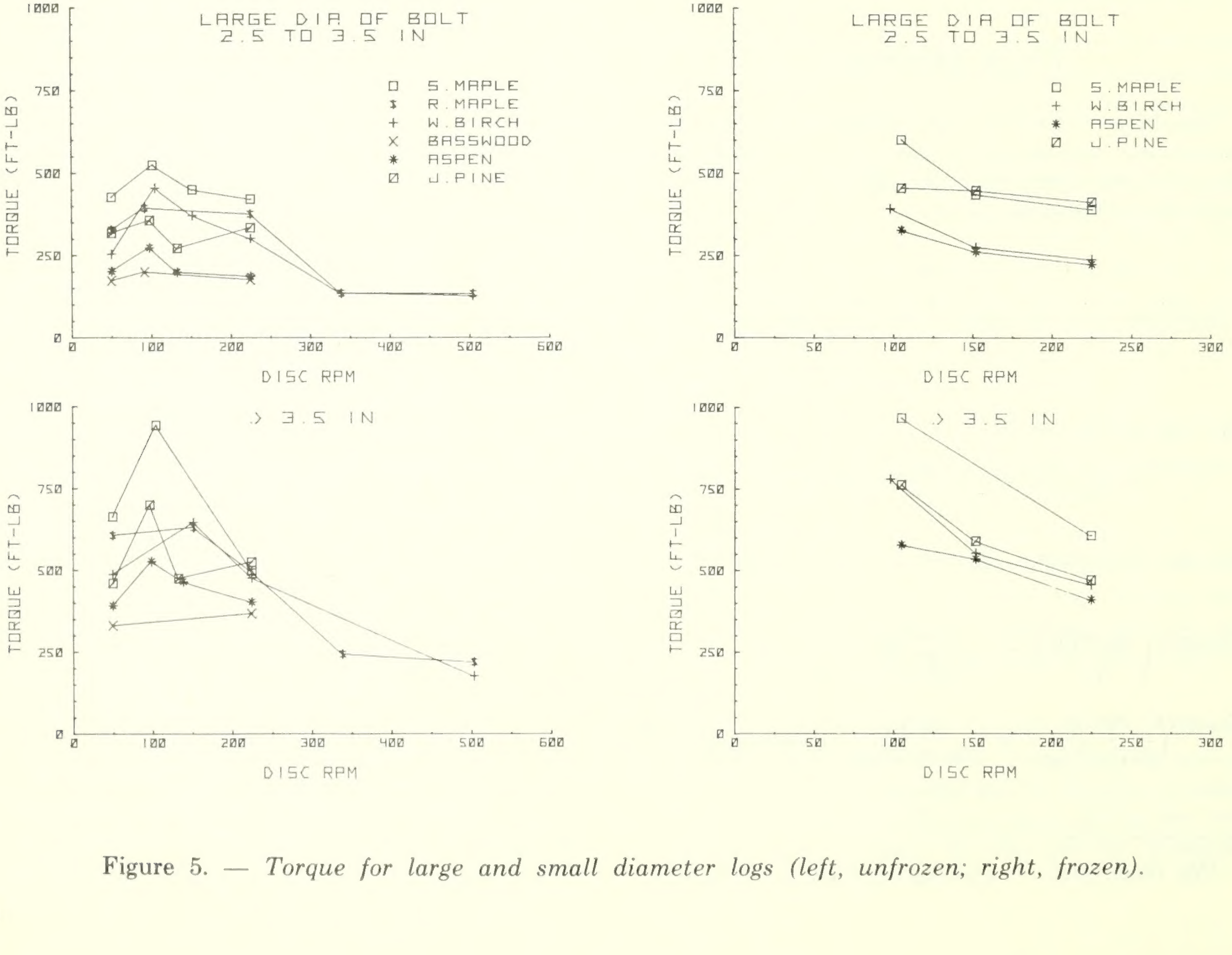

Figure 5. — *Torque for large and small diameter logs (left, unfrozen; right, frozen).*

6.8 hp-min/cu ft as the bolt size increased over the range indicated.

Horsepower is a product of rpm and torque; hence, factors affecting torque also affect horsepower (fig. 6).

The limited power of the prototype machines restricted bolt diameter that could be processed. Bolts larger than 3.5 inches in diameter required twice as much horsepower as those from 2.5 to 3.5 inches. In some cases, the horsepower used was greater than the theoretical 25 hp supplied, with additional power coming from the flywheel effect of the disc. However, 88 of the 700 test bolts could not be chipped because of insufficient power.

For user convenience, two sets of graphs showing the energy required to produce the wood chunks are included. One set presents energy required in terms of cubic feet of wood (fig. 7) while the second set shows the energy required to produce oven-dry tons (fig. 8). The apparent difference in energy levels for each species is due to the various wood density and moisture contents. The graphs show the strong effect of disc rpm as well as the influence of diameter and frozen versus unfrozen condition.

Chunk Output

The experimental involuted disc machine produces large wood chunks that may be of preferred size for certain types of solid fuel, large scale industrial combustors, and perhaps certain gasifiers.

Because of its effect on storage, handling, and heating value, the bulk density of these large chunks is of interest. To determine the bulk density of these chunks, a 36 cu ft box was pre-calibrated to read cubic foot volume when the chunks were leveled in the box. The entire box with chunks was weighed and the box's weight deducted to give the green weight of chunks. The bulk density was obtained by dividing the recorded green weight of chunks in the box by the cubic-foot volume:

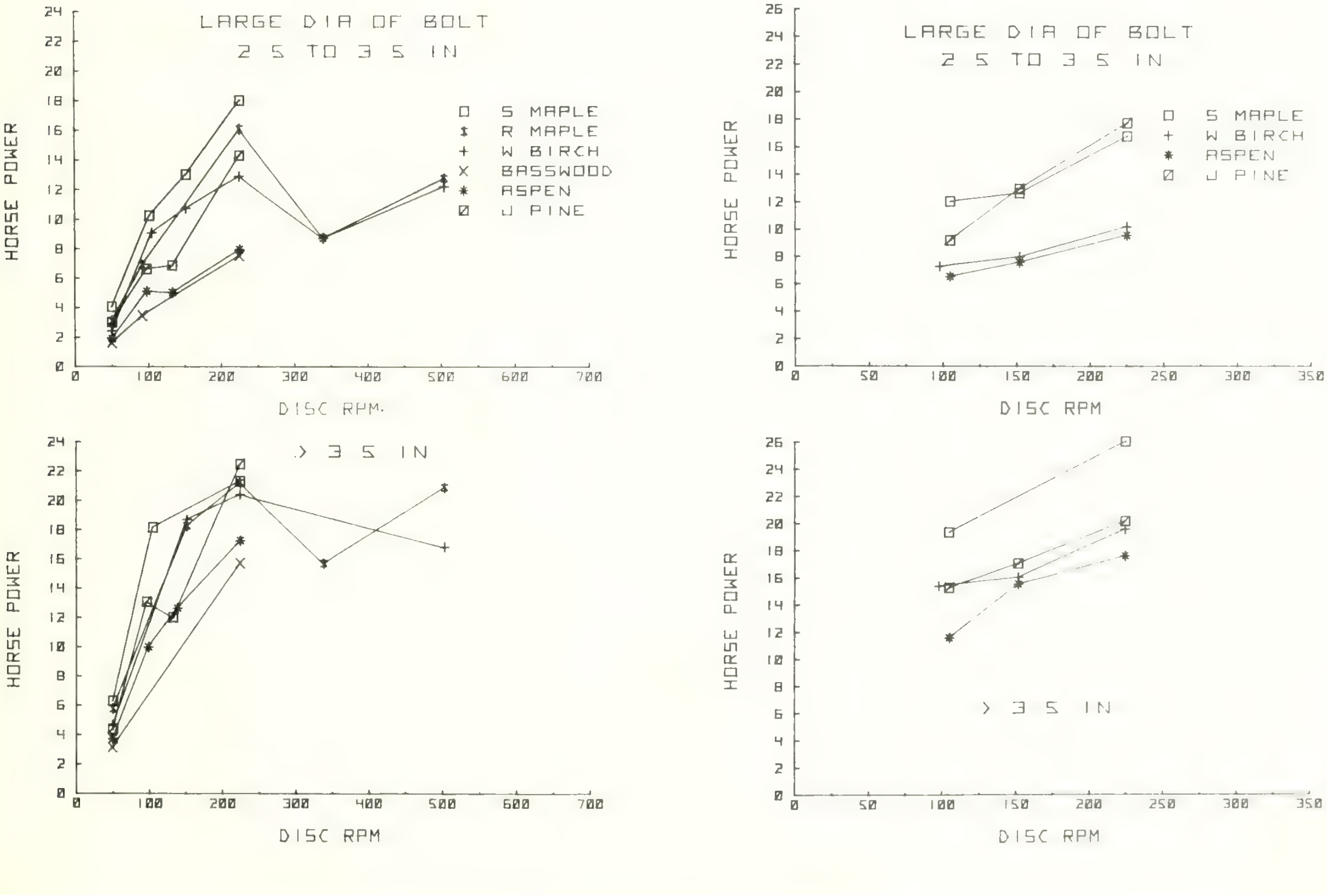

Figure 6. — *Horsepower to chunk large and small diameter logs (left, unfrozen; right frozen).*

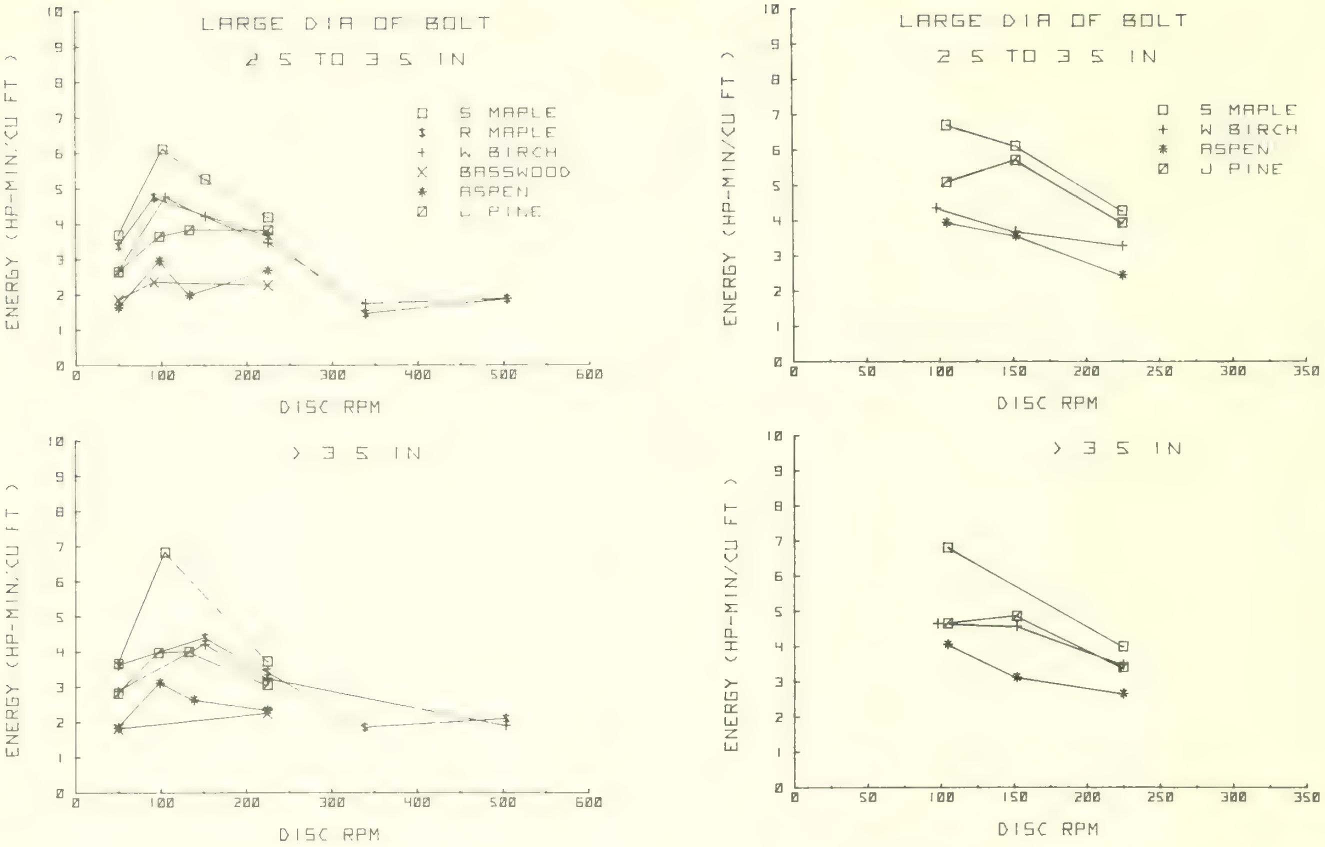

Figure 7. — *Energy for involuted disc chunker - large and small diameter logs (left, unfrozen; right, frozen).*

Species	Average bulk density	Solid volume[2]
	(lb/ft³)	*(Percent)*
Basswood	16.1	38
Aspen	23.4	48
Jack pine	21.2	42
White birch	24.0	42
Red maple	22.1	44
Sugar maple	25.4	44

Conventional green whole-tree chips have a bulk density of 15 to 18 pounds per cubic foot (University of Washington n.d.).

The chunks differed somewhat in size depending on species and on whether the material was unfrozen or frozen at time of chunking — many of the pieces were entire discs, like oversize hockey pucks. These chunks had some internal fracturing along the grain which facilitates subsequent reduction in size or drying of the blocks. Processing of frozen wood, although requiring up to 30 percent more energy, produced particles with much greater internal fracturing.

Though not completely uniform, the chunks or discs from the experimental machine are about 2 inches long, with a maximum cross-section equal to the diameter of the bolt. For certain types of combustors, these discs may still be too large. They are definitely too large to be ring flaked as furnish for flakeboard. To further reduce them in size, they were passed through a modified hammermill, and screened on a round-hole Williams Classifier (table 1). The moisture content of the resulting "fingerling" particles was also determined.

Most wood segments were cut from the test bolts to the specified fiber length. The subsequent hammermilling does not affect the length of particles — only their cross-sectional size (fig. 9). The hammermilled output is still suitable for fuel. Of key importance, quality ring flakes for making structural grade flakeboard can be produced from the particles elongated in the grain direction. As can be seen from

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[2] *Percent solid volume = green weight/cu ft of chunks divided by green weight/cu ft solid wood.*

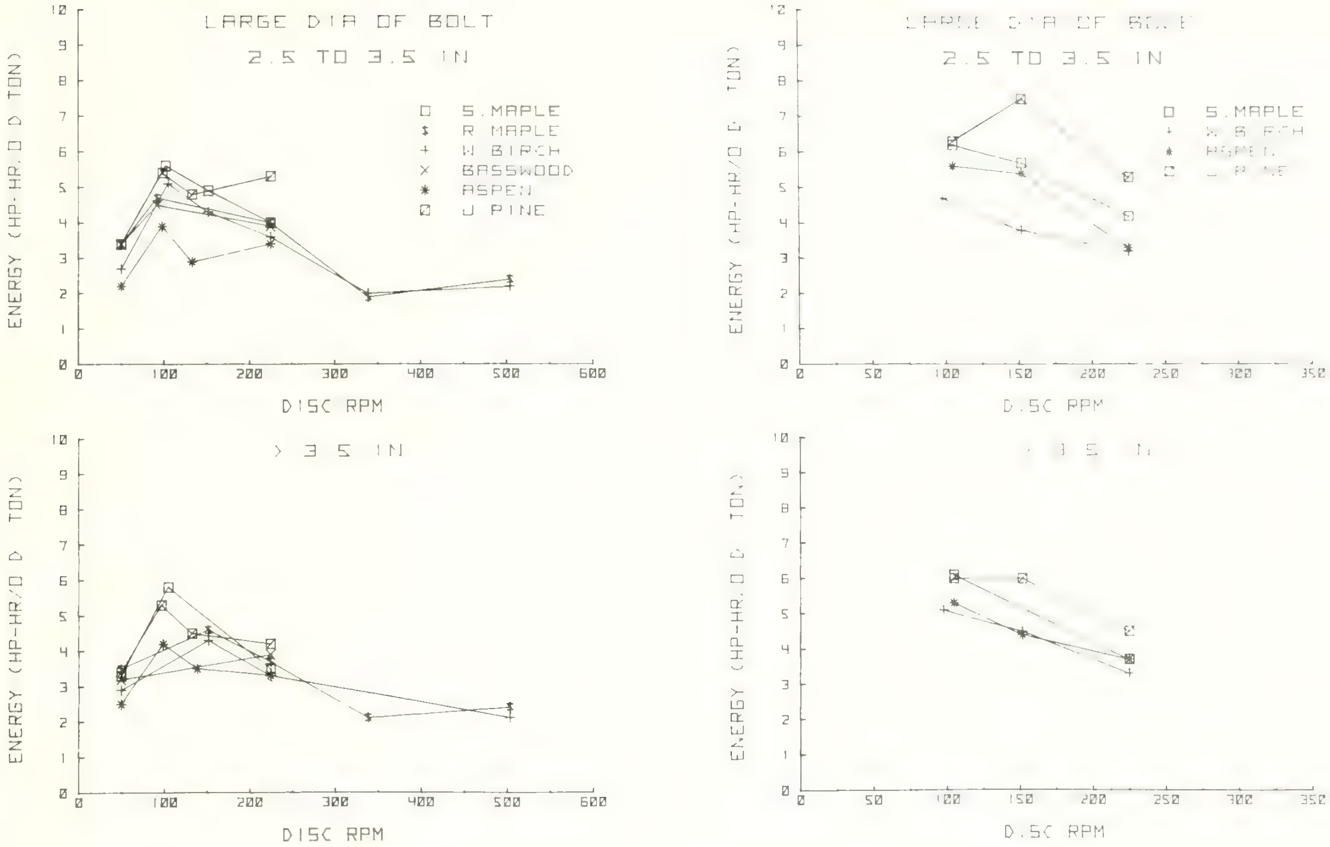

Figure 8. — *Chunker energy in terms of oven-dry tons (left, unfrozen; right, frozen).*

the screen analysis (table 1), most of the particles (85 to 95 percent depending on species) were retained on the 5/8-inch or larger screen. The particles still remained about 2-1/2 inches long for the 3/8-inch and larger screen fractions (fingerlings). It is these elongated particles from which quality ring flakes can be made.

Table 1. — *Screening analysis and moisture content of hammermilled output*

	Hammermilling and screening breakdown (inches)						Moisture content
	+1-1/8	5/8	3/8	3/16	Fines	Total	
	Percent of input						Percent
Basswood	82	12	3	2	1	100	53
Aspen	70	18	6	4	2	100	51
Jack pine	60	25	8	5	2	100	51
White birch	74	19	4	2	1	100	43
Red maple	75	20	3	1	1	100	39
Sugar maple	81	13	3	2	1	100	37

CONCLUSION

Preliminary tests of this experimental disc chunker demonstrated the technical feasibility of producing chunkwood from small diameter wood.

This preliminary research was considered successful enough to warrant the design of a second prototype. Changes include a more adequate power source, which was the limiting factor in this investigation, and the ability to handle logs of larger diameter. Testing of the second prototype will be reported in the future.

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Barwise, Robert D., Rodger A. Arola, and John R. Erickson. 1977. Helical head comminuting shear. U.S. Patent 4,053,004. October 11.

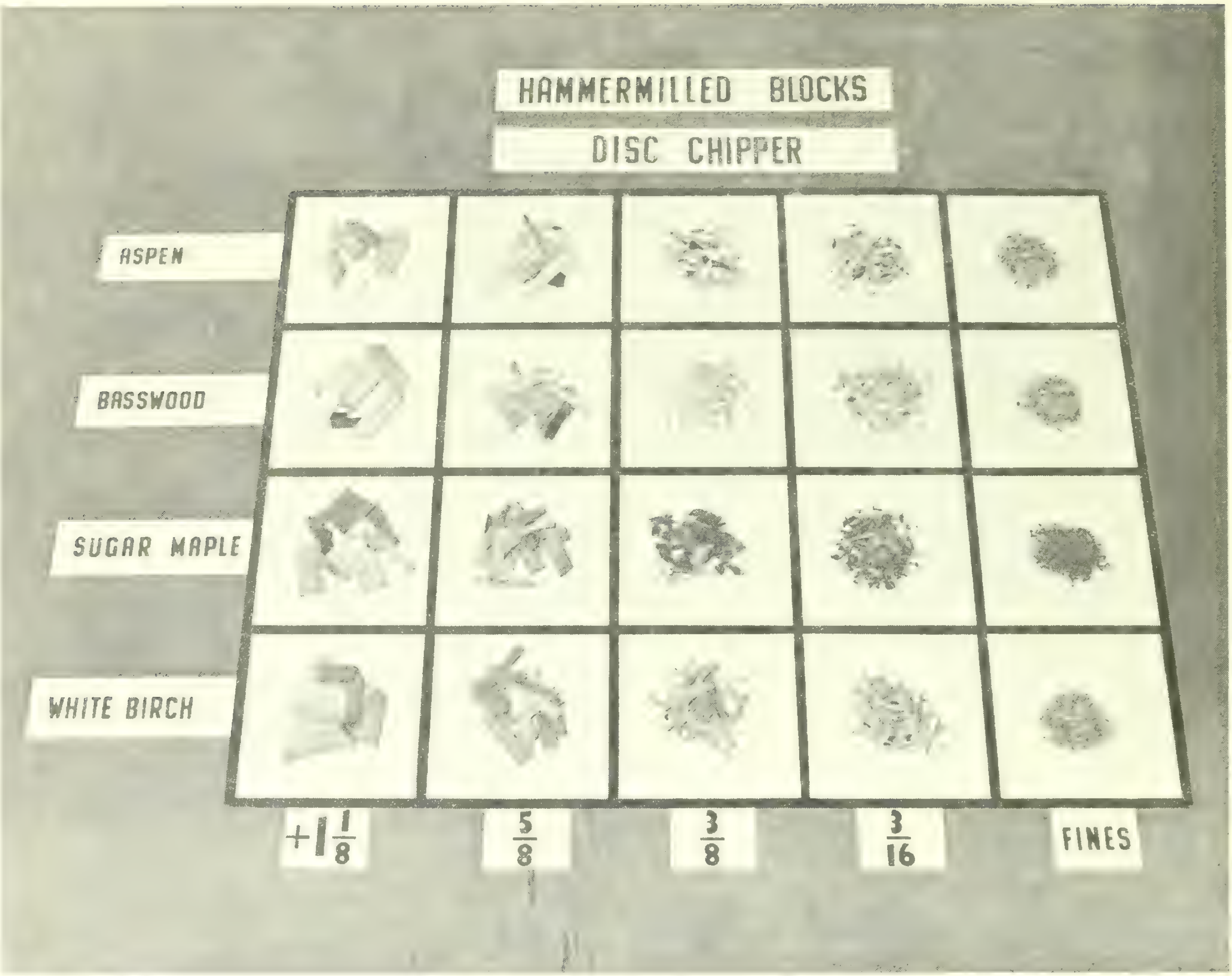

Figure 9. — *Sample particles after hammermilling of chunks.*

Erickson, John R. 1976. Exploratory trials with a spiral-head chipper to make hardwood "fingerling" chips for ring flakers. Forest Products Journal 26(6):50-53.

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Arola, Rodger A., Robert C. Radcliffe, Sharon A. Winsauer, and Edsel D. Matson.

1982. A new machine for producing chunkwood. U.S. Department of Agriculture Forest Service, Research Paper NC-211, 8 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Describes and presents the results of performance testing for an experimental machine that produces chunky wood particles. These wood chunks can be used by the flakeboard industry or as energy wood.

KEY WORDS: Energy wood, flakeboard industry, wood comminution, wood conversion, chipping.

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United States Department of Agriculture

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North Central Forest Experiment Station

Research Paper **NC-212**

A Program and Documentation for Simulation of a Rubber-Tired Feller/Buncher

Sharon A. Winsauer and Dennis P. Bradley

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Winsauer, Sharon A.; Bradley, Dennis P.
A program and documentation for simulation of a rubber-tired feller/buncher. Res. Pap. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 34 p.

Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate and study the productivity and in-woods operation of a rubber-tired feller/buncher.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota. 55108
Manuscript approved for publication April 12, 1982
1982

A PROGRAM AND DOCUMENTATION FOR SIMULATION OF A RUBBER-TIRED FELLER – BUNCHER

Sharon A. Winsauer, *Computer Specialist,*
Houghton, Michigan,
and **Dennis P. Bradley,** *Principal Economist,*
Duluth, Minnesota

Computer modeling of forest harvesting systems has many applications, each requiring a different approach to simulation. Simulations range from technical descriptions of the machine components for equipment design to overviews of large systems where the model estimates the changes in productivity caused by major system changes. The Forestry Sciences Laboratory personnel at Houghton, Michigan, have been developing harvesting simulators as a forest engineering research tool for several years (Bradley *et al.* 1976; Bradley and Winsauer 1976, 1978; USDA Forest Service 1978; Winsauer 1980).

The purpose of this paper is to document a computer model for a rubber-tired, frame-steered feller/buncher (fig. 1). The model was developed to provide a detailed study of the machine's operation in the woods during felling and bunching. It allows the user to determine cost and productivity under various stand and harvest conditions, ways to increase machine efficiency, or to study the effect of changing harvest patterns on cost and productivity Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

THE EQUIPMENT STUDIED

The feller/buncher simulated is a rubber-tired frame-steered chassis with a shear mounted on the front. The shear accumulator can hold one or more trees, but the machine must drive up to each tree to fell it.

MODEL OBJECTIVES

The primary objective of this model is to allow a detailed study of the productivity and operation of the feller/buncher in the woods. For input, the model requires data on the machine's operating characteristics, the stand, and the type of harvest to be carried out.

After simulating the harvest of a plot, the model reports productivity figures such as: trees, tons and volume per hour and per load, total cycles, tree per cycle, distance traveled, and skid bunches completed.

Additional output gives details of the woods operation, distributions of cycle times, distances, number of trees per bunch, size of skidder bunches, frequency and length of delays, etc.

SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation Language (GPSS) with output subroutines written in FORTRAN. GPSS is a discrete event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up from a group of specific GPSS block types. These blocks then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

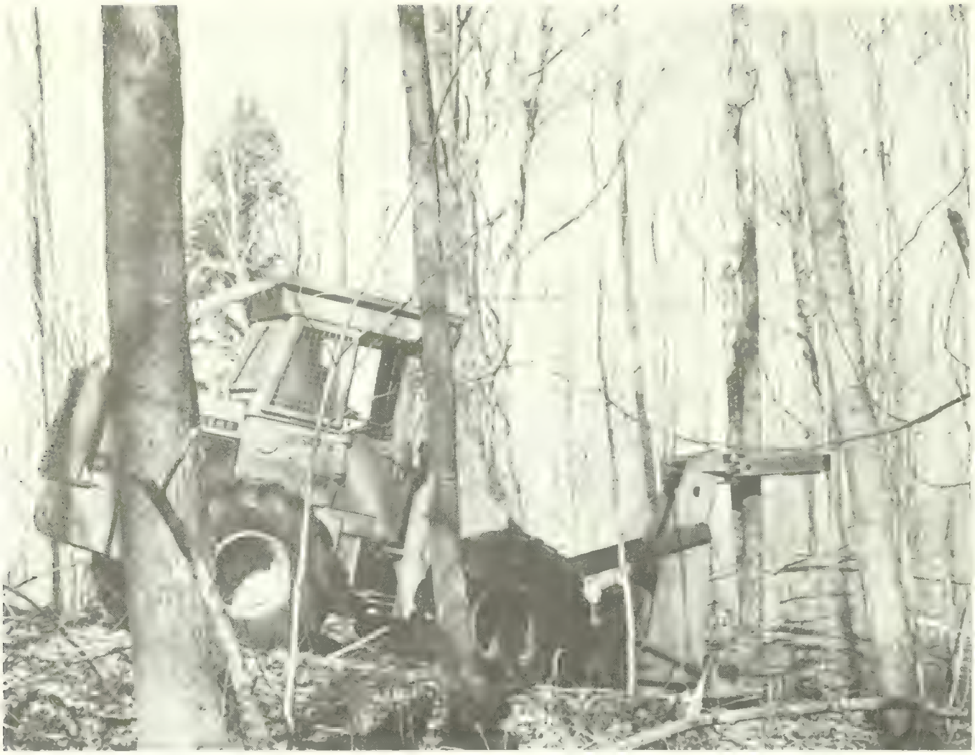

Figure 1.—*Typical rubber-tired type feller/buncher.*

Most versions of GPSS have a standard output format that contains allthe data in a very concise form. The FORTRAN subroutines are used to present the output values of most interest in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a centiminute; i.e., 1/100 of a minute. The feller works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot.

It is assumed that the feller/buncher operates in an area far enough in advance of the skidder to minimize interactions between machines. To simulate a hot logging operation, this model can be combined with a complete skidding-chipping or skidding-loader model. Another alternative would be to add a "black box" skidder segment, a simplified segment, used to create the machine interactions without providing a detailed study of the skidder operation.

Since an efficient skidder load usually contains more trees than the shear can hold, the feller/buncher may shear and drop several loads at one location to create the skidder bunch.

The following assumptions are made about the feller/buncher's behavior:

1. A feller/buncher cycle is defined as starting after a load is dropped and ending when the next load is dropped.
2. The machine has an accumulating shear. (The model can easily be changed to single head shear by limiting the accumulator load to one.).
3. The feller/buncher must move up to each tree to shear it. It travels back and forth across a relatively narrow strip of forest, cutting trees marked for cutting as it encounters them, working its way along the trip until the far end of the plot is reached. It then moves to the next strip and repeats the process (fig. 2).
4. The feller will cut and accumulate multiple trees before dropping them. It will drop the accumulator head load when the accumulator head is full or if the next tree to cut is too far away.
5. When the feller must drop the trees held in the accumulator head, it will carry the load to the partial bunch and drop the trees there. If no partial skidder bunch has been started or if the partial bunch is judged to be too far away, it will drop them at the location of the last tree cut.

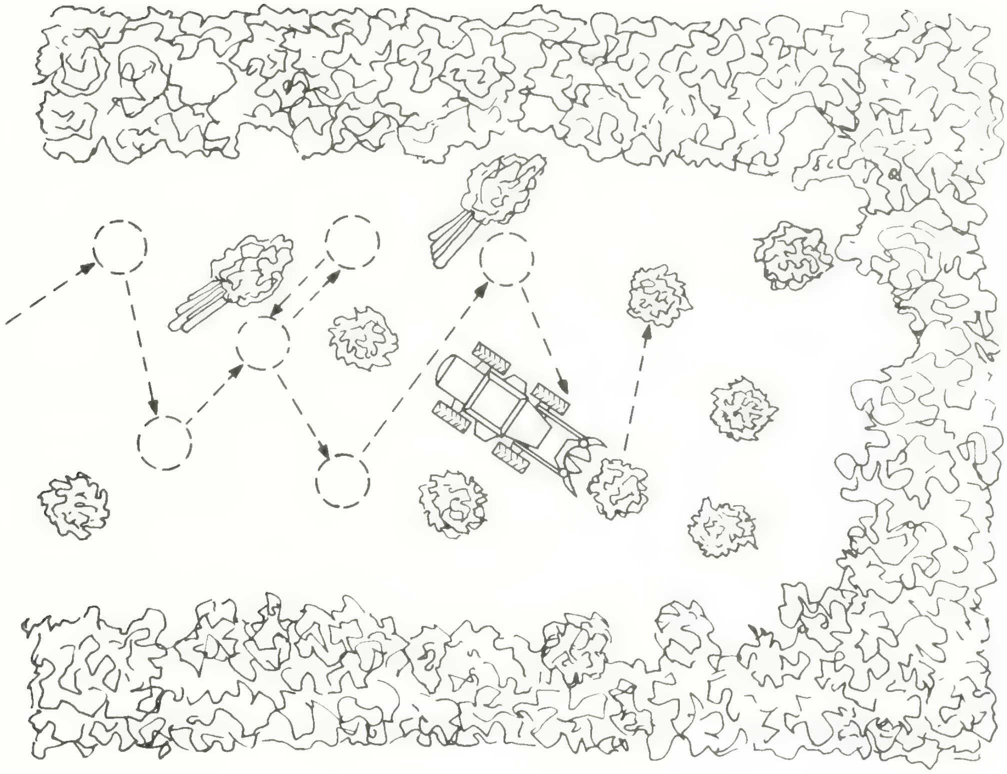

Figure 2.—*Feller/buncher travel pattern.*

6. The feller/buncher operator can quit for the day or stop for a break only after dropping the trees in the accumulator head.
7. Mechanical and nonmechanical delays for the feller are also incorporated into the model. For ease of programming, they are assumed to occur in a cycle after the feller/buncher drops the current load of trees.

MODEL DESCRIPTION

The model consists of two GPSS segments:

1. TIMER SEGMENT
2. FELLER/BUNCHER SEGMENT

and two FORTRAN subroutines for formatted (easily read) output.

The TIMER SEGMENT (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines to produce the formatted output. The TIMER signals the start of the day, the rest breaks and lunch (two 15-minute breaks a day and ½-hour lunch are assumed), and the end of the workday. The TIMER then completes the 24-hour day and produces an output report of the previous day's operation and production. Output is produced at the end of 24 hours, not at the end of the shift, to include the time needed for the feller to complete the bunch being worked on before quitting for the day. If the required number of days have been simulated, the model shuts off. Otherwise, the start of another workday is signaled, and the process continues.

The FELLER/BUNCHER SEGMENT (fig. 4) models a rubber-tired, frame-steered feller/buncher with an accumulating head shear mounted on the front. The machine must move up to each tree to cut it.

It moves through the woods along a strip but travels back and forth within the strip in order to reach the trees to be cut. The feller/buncher attempts to create bunches large enough to be skidded economically.

DATA NEEDS

GPSS accepts machine and stand data in several forms (table 1). For additional information on data types and card formats, see a GPSS Programming Manual (Schriber 1974).

Most of the data required in the main program are expected in the form of GPSS VARIABLES. These VARIABLES are then defined at the end of the deck in terms of the available machine and stand data.

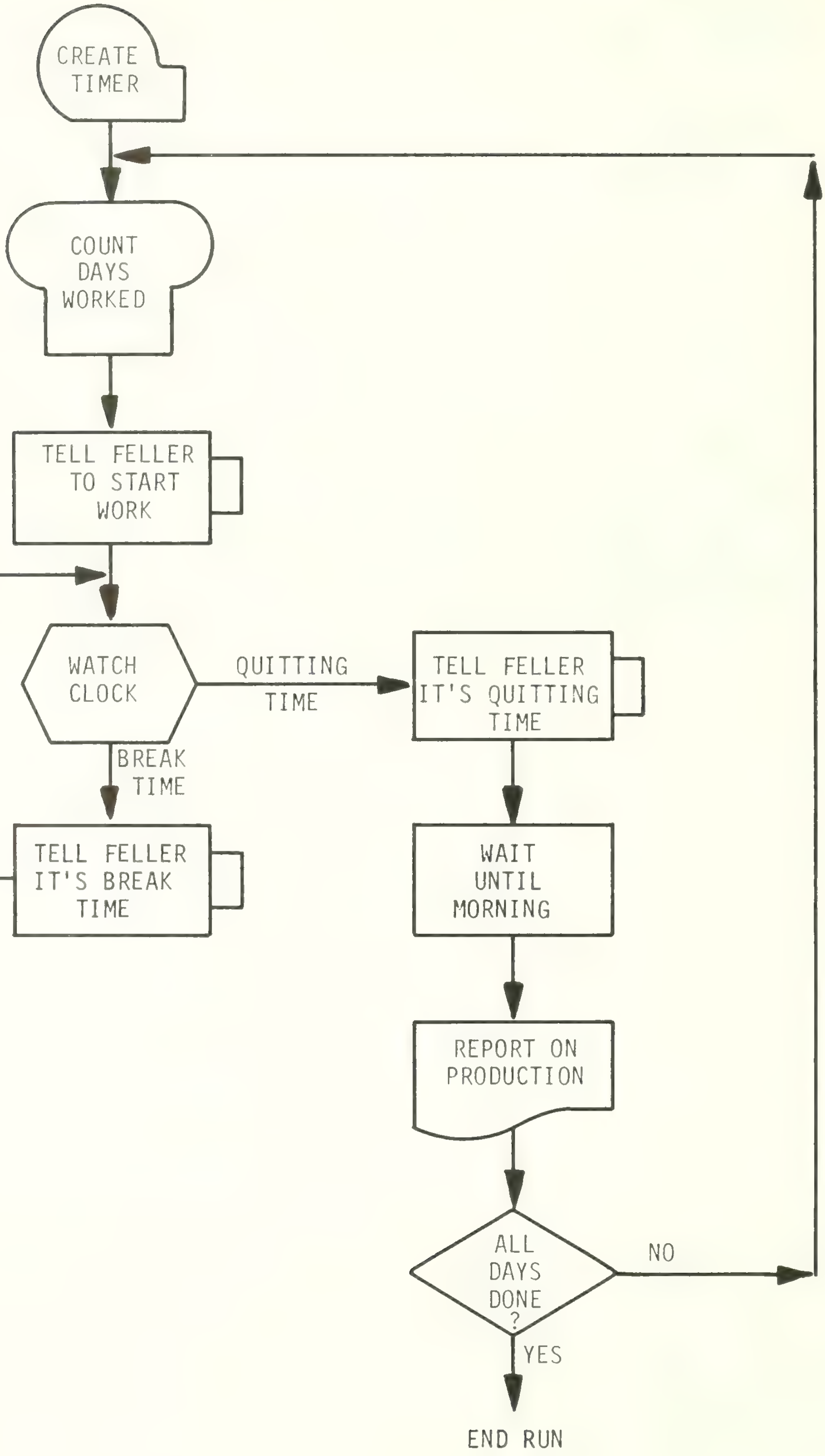

Figure 3.—*Timer segment—overview.*

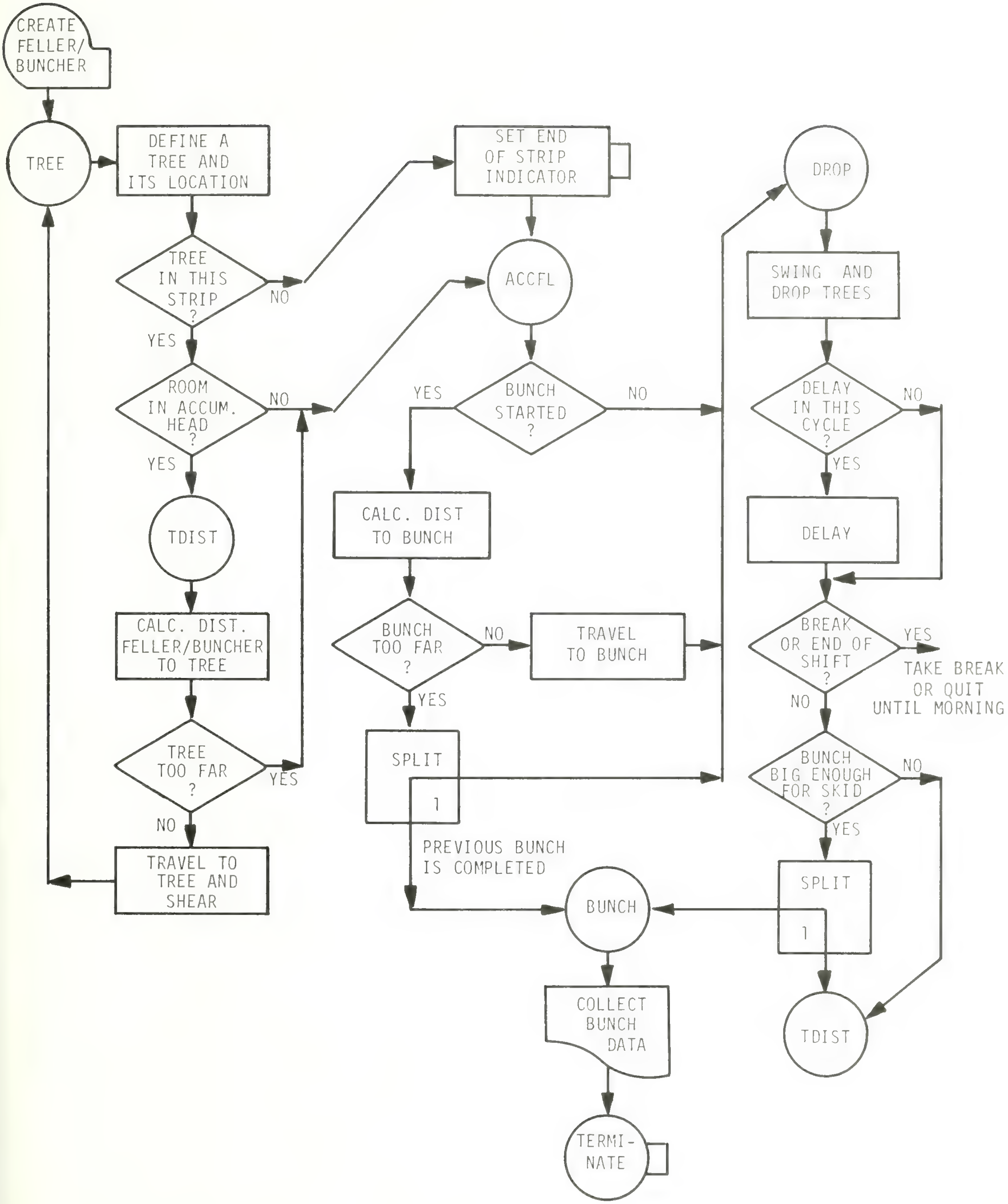

Figure 4.—*Feller/buncher segment—overview.*

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Table 1.—*PSS data input forms*

Input data type	Input form in GPSS	Example
Simple averages or constants	Initialized SAVEVALUES	Ave d.b.h. = inches
Range of values	Initialized SAVEVALUES for mean and ½ width of interval	Shear Time = 10 to 14 c min = 12 ± 2 c min
Equations	VARIABLES	Volume = .13 d.b.h.^{2} − .28
Frequency distributions	FUNCTIONS	D.B.H. (in) 4 5 6 7 8 Percent trees 23 25 30 15 5
Mean and variance for a standard distribution such as normal, poisson exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with mean = 10 variance = 9

This allows the user flexibility in data form while avoiding card shuffling in the main program For example, changing a shear time from a constant (GPSS SAVEVALUE) to a frequency distribution (GPSS FUNCTION) is accomplished by simply redefining the shear time VARIABLE and supplying the appropriate cards .

The input data cards follow the VARIABLE definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition. An exception to this convention is the use of GPSS SAVEVALUES (constants) merely for summary purposes (average stand d.b.h., average tree height, etc.).

Four types of data describing the equipment and harvesting operation must be supplied.

1. Stand data (table 2).
2. Machine data dependent upon stand conditions (table 3).
3. Machine data (independent of stand) (table 4).
4. Simulation run control (table 5).

The output example presented in this paper uses the information in tables 2 through 5 as input. These data were gathered from time studies carried out during Forest Service case studies. The data in the tables are empirical, so they represent the operating characteristics of this machine under the stand conditions found during the time studies. Different harvest conditions may require new time study data.

SIMULATION OUTPUT

The simulation run produces two pages of formatted output for each day of the run (figs. 5 and 6). These present a summary of the stand data and a cumulative productivity report.

Additional, standard GPSS output is produced at the end of the run by the GPSS processor and supplies complete run details (fig. 7).

The first page of the standard output presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is of primary value while debugging the model. The listing of the QUEUE sta-

Table 2.—*Stand data*

<table>
<tr><th>Data required</th><th colspan="11">Case study</th><th>Form required by program</th><th>Name</th></tr>
<tr><td>Average stand diameter</td><td colspan="11">5.1 in d.b.h.</td><td>SAVEVALUE</td><td>X$AVDBH</td></tr>
<tr><td>Average stand volume</td><td colspan="11">2,842 cu ft./acre</td><td>SAVEVALUE</td><td>X$AVVOL</td></tr>
<tr><td>Average tree height</td><td colspan="11">60 ft</td><td>SAVEVALUE</td><td>X$AVHGT</td></tr>
<tr><td>Average trees/acre</td><td colspan="11">550 trees/acre (all sizes)</td><td>SAVEVALUE</td><td>X$TRPAC</td></tr>
<tr><td>Strip length</td><td colspan="11">660 ft</td><td>SAVEVALUE</td><td>X$STPLN</td></tr>
<tr><td>Distance between strips</td><td colspan="11">32 ft</td><td>SAVEVALUE</td><td>X$MVSTP</td></tr>
<tr><td>Density of wood</td><td colspan="11">55 lb/cu ft</td><td>SAVEVALUE</td><td>X$LBCFT</td></tr>
<tr><td>Hours in daily work shift</td><td colspan="11">8 hours</td><td>SAVEVALUE</td><td>X$WKDAY</td></tr>
<tr><td>Actual tree diameter</td><td colspan="11">Diameter distribution</td><td>SAVEVALUE</td><td>V$TDIAD</td></tr>
<tr><td></td><td>d.b.h. (in.)</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td><td>12</td><td>14</td><td>16</td><td>18</td><td>20</td><td></td><td></td></tr>
<tr><td></td><td>Percent trees</td><td>25.4</td><td>22.5</td><td>30.4</td><td>8.6</td><td>6.3</td><td>3.2</td><td>2.0</td><td>1.1</td><td>.4</td><td>.2</td><td></td><td></td></tr>
<tr><td>Volume of trees</td><td colspan="11">Volume of trees (cu ft)
Volume = −0.283 + 0.0031 (d.b.h.^{2}) tree height
= −0.283 + 0.186 (d.b.h.^{2})</td><td>VARIABLE</td><td>V$TVOL</td></tr>
</table>

Table 3.—*Machine data dependent on stand conditions*

Date required	Case study	Form required by program	Name
Expected X coordinate of the next tree to be cut	X coordinate equally likely to fall anywhere in the strip X coordinate = strip width X (Rand #1) + 1	VARIABLE	V$XCORD
Expected Y coordinate of the next tree to be cut[1]	Distribution of the difference in feet (next tree's Y coordinate—current tree's Y coordinate)	VARIABLE	V$YCORD

Y DIF	0	2	4	6	8	10	12	14	16	18
Percent trees	18	30	16	12	8	4	4	3	3	2

Date required	Case study	Form required by program	Name
Maximum distance feller will travel to add another tree to accumulator head	8 feet	SAVEVALUE	X$ADLIM
Maximum distance feller will travel to add additional trees to a partial bunch	45 feet	SAVEVALUE	X$BDLIM

---

[1] The empirical distribution of the expected location for the next tree to be cut could be replaced with an analytic function (Bradley, Dennis P. An analytical procedure to locate trees for simulated tree harvest, (manuscript in process).

Table 4.—*Machine data*

Data required	Case study	Form required by program	Name
Travel time (based on distance)	Travel speed Mean = 150 ft/min St. dev. = 50 ft/min	VARIABLE	V$FBTRAV
Shear time per tree	Shear time Mean = 25 centi-min St. dev. = 12 centi-min	VARIABLE	V$FBSHR
Drop time per load	Drop time Mean = 15 centi-min St. dev. = 9 centi-min	VARIABLE	V$FBDRP
Maximum size of skidder bunch the feller creates (sum total of diameters)	Bunch diameter limit 45 inches	VARIABLE	V$BUNLM
Gal/hr fuel used	4.7 gal hr	SAVEVALUE	X$FBGPH
Length of nonmechanical delay per cycle (including cycles with zero delay)	Distribution of nonmechanical delays (min)	VARIABLE	V$NMDLY

LENGTH OF DELAY	0	0-1	1-2	2-5	5-10	10-20	20-50
Percent of cycles	97.3	.9	.5	.5	.4	.3	.1

Data required	Case study	Form required by program	Name
Length of mechanical delay per cycle (including cycles with zero delay)	Distribution of mechanical delay (min)	VARIABLE	V$MCDLY

LENGTH OF DELAY	0	0-5	5-10	10-50
Percent of cycles	99.4	.2	.2	.2

Table 3.—Simulation run parameters

Data required	Case study	Form required by program	
Random number generators	Random number 1	Use for GPSS scheduler	RMULT card
	2	generate normal random distribution	
	3	tree location distribution	
	4	d.b.h. distribution	
	5	not used	
	6	delay distributions	
Number of days	5 days		
Standard output	every 5th day		Start card

tistics provides detailed information on how the feller buncher spends its time in the woods. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used.

Example:

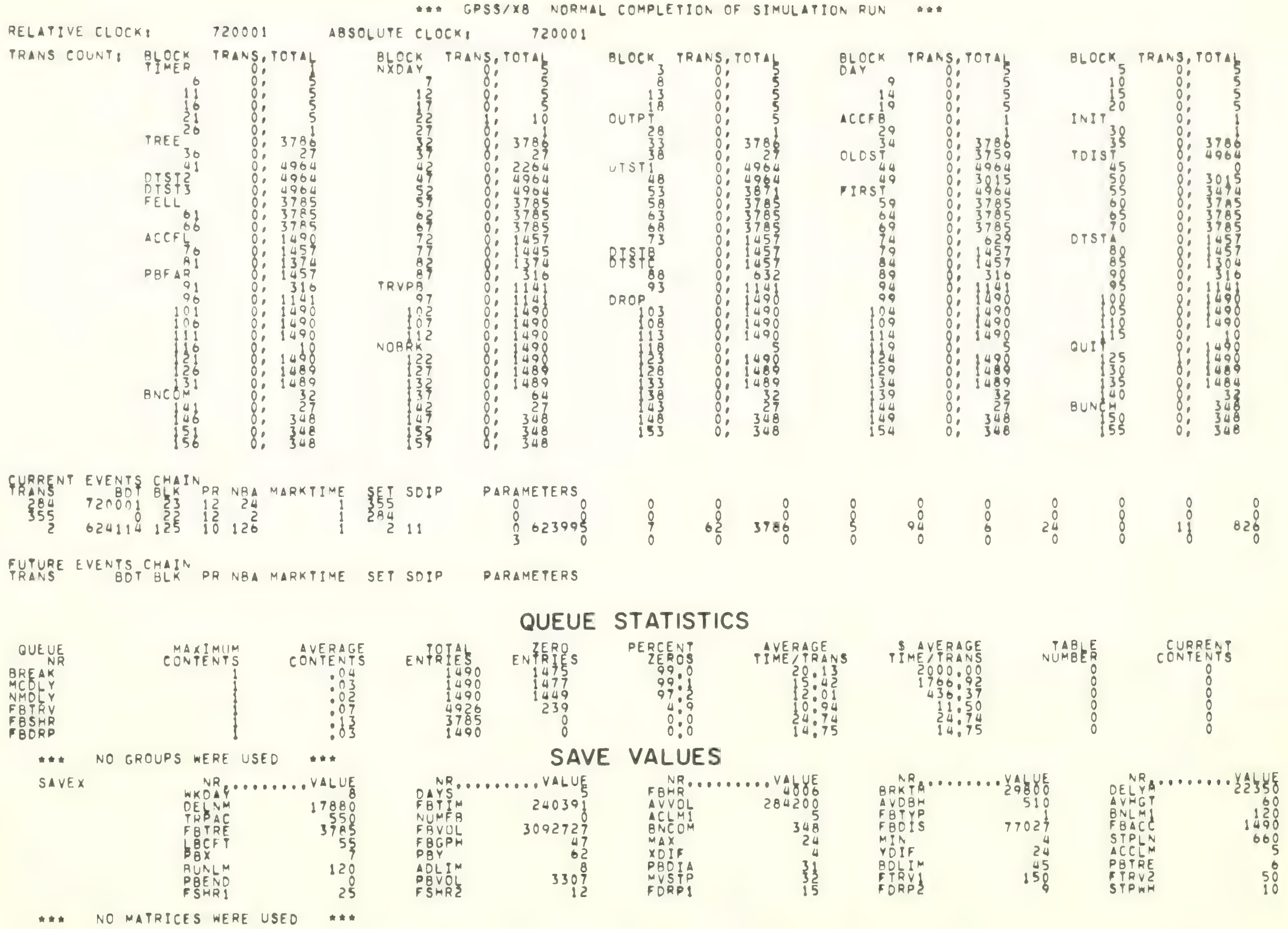
FBHR = 4.006 = feller hours × 100
FBTRE = 3.785 trees cut
3.785/40.06 = 94.48 trees/hour

```
                          FULL  TREE  FIELD  CHIPPING  SIMULATOR
                                   DEVELOPED  BY  THE
                         NORTH CENTRAL FOREST EXPERIMENT STATION
                        FOREST  SERVICE, U. S. DEPT.  OF  AGRICULTURE

            FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                         AND THE
                      FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN

                                         AUTHORS
                              DENNIS P. BRADLEY, ECONOMIST
                             SHARON A. WINSAUER, PROGRAMMER

 STAND CHARACTERISTICS.

  2844.00 CU FT. AVERAGE VOLUME PER ACRE.
     9.10 INCHES. AVERAGE DBH.
    60.00 FEET. AVERAGE TREE HEIGHT.
   580.00 AVERAGE NUMBER OF TREES PER ACRE.
     8.67 FEET. AVERAGE TREE SPACING.

  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
.  FELLER-BUNCHER.                      1  MACHINE     RUBBER-TIRED TYPE
    MACHINE LIMITATIONS.
      THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN A LOAD OF UP TO    5.0 TREES
    BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:
      THE FELLER-BUNCHERS TRY TO ACHIEVE SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO 120.0 INCHE
```

Figure 5.—Simulation output—system and stand characteristics.

```
   F E L L E R - B U N C H E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y
*****************************************************************************************************************


I.    A.   40.06      HOURS WORKED BY FELLER-BUNCHER INCLUDING
                298.00      MINUTES OF PERSONAL BREAKS,
                223.50      MINUTES MECHANICAL DELAY,
                178.80      MINUTES NON-MECHANICAL DELAY
      B.       1      FELLFR-BUNCHER.     RUBBER-TIRED TYPE.

II.   A.    1490      TOTAL ACCUMULATOR CYCLES COMPLETED - ALL MACHINES.
                  2.54      AVERAGE NUMBER OF TREES PER CYCLE.
                 20.76      AVERAGE VOLUME PER CYCLE - CU.FT.
      B.     348      BUNCHES COMPLETED
                 10.88      AVERAGE NUMBER OF TREES PER BUNCH.
                  4.28      AVERAGE NUMBER OF CYCLES PER BUNCH.
                 88.87      AVERAGE VOLUME PER BUNCH - CU.FT.
      C.    3785      TOTAL TREES FELLED.
      D. 30927.3      TOTAL VOLUME FELLED - CU.FT.
      E.  850.50      TOTAL TONS FELLED
      F.   77027      TOTAL DISTANCE TRAVELED - FEET

III.  A.   37.19      AVERAGE NUMBER OF CYCLES PFR MACHINE HOUR.
      B.    8.69      AVERAGE NUMBER OF BUNCHES COMPLETED PER MACHINE HOUR.
      C.   94.48      AVERAGE NUMBER OF TREES FELLED PER MACHINE HOUR.
      D.  772.02      AVERAGE VOLUME FELLED PER MACHINE HOUR.
      E.   21.23      AVERAGE NUMBER OF TONS FELLED PER MACHINE HOUR.
      F. 1922.79      AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.

IV.   A.  188.28      TOTAL GALLONS OF FUEL USED BY THE FELLER-BUNCHER.
                  4.70      GALLONS PER HOUR.
                   .22      GALLONS PER TON.
                   .61      GALLONS PER CUNIT.
```

Figure 6.—*Simulation output—productivity.*



```
                                          ***  GPSS/X8  NORMAL COMPLETION OF SIMULATION RUN   ***
RELATIVE CLOCK:      720001      ABSOLUTE CLOCK:      720001
TRANS COUNT:  BLOCK  TRANS,TOTAL     BLOCK  TRANS,TOTAL     BLOCK  TRANS,TOTAL     BLOCK  TRANS,TOTAL     BLOCK  TRANS,TOTAL
              TIMER      0,     1    NXDAY      0,     5         3     0,     5    DAY        0,     5         5     0,     5
                  6      0,     5        7      0,     5         8     0,     5         9     0,     5        10     0,     5
                 11      0,     5       12      0,     5        13     0,     5        14     0,     5        15     0,     5
                 16      0,     5       17      0,     5        18     0,     5        19     0,     5        20     0,     5
                 21      0,     5       22      1,    10    OUTPT      0,     5    ACCFB      0,     1    INIT       0,     1
                 26      0,     1       27      0,     1        28     0,     1        29     0,     1        30     0,     1
              TREE       0,  3786       32      0,  3786        33     0,  3786        34     0,  3786        35     0,  3786
                 36      0,    27       37      0,    27        38     0,    27    OLDST      0,  3759    TDIST      0,  4964
                 41      0,  4964       42      0,  2264    DTST1      0,  4964        44     0,  4964        45     0,     0
              DTST2      0,  4964       47      0,  4964        48     0,  4964        49     0,  3015        50     0,  3015
              DTST3      0,  4964       52      0,  4964        53     0,  3871    FIRST      0,  4964        55     0,  3474
              FELL       0,  3785       57      0,  3785        58     0,  3785        59     0,  3785        60     0,  3785
                 61      0,  3785       62      0,  3785        63     0,  3785        64     0,  3785        65     0,  3785
                 66      0,  3785       67      0,  3785        68     0,  3785        69     0,  3785        70     0,  3785
              ACCFL      0,  1490       72      0,  1457        73     0,  1457        74     0,   629    DTSTA      0,  1457
                 76      0,  1457       77      0,  1445    DTSTB      0,  1457        79     0,  1457        80     0,  1457
                 81      0,  1374       82      0,  1374    DTSTC      0,  1457        84     0,  1457        85     0,  1304
              PBFAR      0,  1457       87      0,   316        88     0,   632        89     0,   316        90     0,   316
                 91      0,   316    TRVPB      0,  1141        93     0,  1141        94     0,  1141        95     0,  1141
                 96      0,  1141       97      0,  1141    DROP       0,  1490        99     0,  1490       100     0,  1490
                101      0,  1490      102      0,  1490       103     0,  1490       104     0,  1490       105     0,  1490
                106      0,  1490      107      0,  1490       108     0,  1490       109     0,  1490       110     0,  1490
                111      0,  1490      112      0,  1490       113     0,  1490       114     0,  1490       115     0,    10
                116      0,    10    NOBRK      0,  1490       118     0,     5       119     0,     5    QUIT       0,  1490
                121      0,  1490      122      0,  1490       123     0,  1490       124     0,  1490       125     1,  1490
                126      0,  1489      127      0,  1489       128     0,  1489       129     0,  1489       130     0,  1489
                131      0,  1489      132      0,  1489       133     0,  1489       134     0,  1489       135     0,  1484
              BNCOM      0,    32      137      0,    64       138     0,    32       139     0,    32       140     0,    32
                141      0,    27      142      0,    27       143     0,    27       144     0,    27    BUNCH      0,   348
                146      0,   348      147      0,   348       148     0,   348       149     0,   348       150     0,   348
                151      0,   348      152      0,   348       153     0,   348       154     0,   348       155     0,   348
                156      0,   348      157      0,   348

CURRENT EVENTS CHAIN
TRANS      BDT BLK  PR NBA MARKTIME  SET SDIP    PARAMETERS
  284   720001  23  12  24        1  355            0       0     0     0     0     0     0     0     0     0     0     0
  355        0  22  12   2        1  284            0       0     0     0     0     0     0     0     0     0     0     0
    2   624114 125  10 126        1    2 11         0  623995     7    62  3786     5    94     6    24     0    11   826
                                                    3       0     0     0     0     0     0     0     0     0     0     0

FUTURE EVENTS CHAIN
TRANS      BDT BLK  PR NBA MARKTIME  SET SDIP    PARAMETERS
```

QUEUE STATISTICS

```
 QUEUE         MAXIMUM     AVERAGE      TOTAL      ZERO    PERCENT    AVERAGE     $ AVERAGE     TABLE     CURRENT
    NR        CONTENTS    CONTENTS    ENTRIES   ENTRIES     ZEROS   TIME/TRANS   TIME/TRANS    NUMBER    CONTENTS
BREAK                1         .04       1490      1475      99.0       20.13       2000.00         0           0
MCDLY                1         .03       1490      1477      99.1       15.42       1766.92         0           0
NMDLY                1         .02       1490      1449      97.2       12.01        436.37         0           0
FBTRV                1         .07       4926       239       4.9       10.94         11.50         0           0
FBSHR                1         .13       3785         0       0.0       24.74         24.74         0           0
FBDRP                1         .03       1490         0       0.0       14.75         14.75         0           0

   ***   NO GROUPS WERE USED   ***
```

SAVE VALUES

```
   SAVEX           NR.........VALUE       NR.........VALUE       NR.........VALUE       NR.........VALUE       NR.........VALUE
                WKDAY             8    DAYS              5    FBHR           4006    BRKTM         29800    DELYA         22350
                DELNM         17880    FBTIM        240391    AVVOL        284200    AVDBH           510    AVHGT            60
                TRPAC           550    NUMFB             0    ACLM1             5    FBTYP             1    BNLM1           120
                FBTRE          3785    FBVOL       3092727    BNCOM           348    FBDIS         77027    FBACC          1490
                LBCFT            55    FBGPH            47    MAX              24    MIN               4    STPLN           660
                PBX               7    PBY              62    XDIF              4    YDIF             24    ACCLM             5
                RUNLM           120    ADLIM             8    PBDIA            31    BDLIM            45    PBTRE             6
                PBEND             0    PBVOL          3307    MVSTP            32    FTRV1           150    FTRV2            50
                FSHR1            25    FSHR2            12    FDRP1            15    FDRP2             9    STPWH            10

   ***   NO MATRICES WERE USED   ***
```

Figure 7.—*Simulation output—standard GPSS form.*

Additional details of the in-woods operations are provided by the GPSS TABLES (figs. 8-10). The cycle time table FBTIM (cycle time starts after the feller/buncher drops one load and ends when it drops the next) shows there were 1,490 cycles with an average cycle time of 161 centi-minutes. Of all 1,490 cycles, 240 cycles or 16 percent took between 100 and 125 centi-minutes .

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves a random sample of what could happen. If the model is run again with different random samples, the exact results will be different but will reflect the underlying means and variance of the system. An average over several days or several runs is the best estimate of an actual system .

RELIABILITY

The simulation described here used data obtained in a previous study of mechanized thinning. Three simulation runs were made using different random number sequences to insure different random samples. Simulated production figures were averaged and compared with the productivity observed during the actual thinning (table 6). The greatest error of 14.7 percent appears in cycles/hour with delay. A portion of this error can be attributed to the simulation runs having a higher percent of productive time on the runs made. Other runs, with different random number sequences, would alter the number and duration of delays, hence the cycles/hour. The comparison indicates the model is a reasonably accurate mirror of the real system. Obviously, the better the input data, the more useful the output!

KNOWN GPSS SYSTEMS DIFFERENCES

The program listed in the Appendix is operational on a UNIVAC 1110 under an implentation of GPSS called GPSS-X8, obtained through Use Program Library Interchange (UPLI). It should run under most GPSS Processors with only minor changes. The following should be checked for your system.

INITIAL cards—In GPSS-X8, the INITIAL cards appear last in the deck.

They should be moved to the head of the deck for most other GPSS processors.

JOB CONTROL cards—These are unique to each computer lab and must be obtained locally.

HELP BLOCKS—In GPSS-X8, HELP BLOCKS (line 65-80 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted, the subroutine cannot pass arguments back to GPSS.

Some versions of GPSS do not allow HELP BLOCKS. In this case, the program can be run without lines 48 to 80 and the data obtained instead from the standard output. If some form of HELP BLOCKS are allowed, the HELP BLOCKS formats and the subroutines may have to be changed. See the GPSS manual for your computer installation.

CONCLUSIONS

Most harvesting system changes have relatively complex effects on productivity. The simulation model provides an in-depth look at the operation of this machine in the woods and makes it possible to study the effect of a change in any one system characteristic or stand factor or many changes at the same time. It can also be combined with a model of skidding and chipping operations to provide productivity information for a whole-tree system. Perhaps the greatest value of a GPSS model is the ease with which it can be modified to suit the exact requirements of your system. Although this requires some knowledge of GPSS, it makes simulation an extremely valuable tool.

Table 6.—*Corroboration of simulated productivity with field data*

Field data and simulated productivity	Productive time worked	Trees per hour		Cycles per hour		Average number trees	
		No delays	With delays	No delays	With delays	/Cycle	Skidbunch
	Percent						
Field data	73	132	94	48	34	2.8	10.1
Simulation runs[1]	78	130	98	51	39	2.5	10.8
(Error)	(6.8)	(−1.5)	(4.1)	(5.8)	(14.7)	(−10.7)	(6.9)

[1] Average of three simulation trials using different random number sequences

CYCLE TIME (CENTI-MINUTES)

```
TABLE            ENTRIES IN TABLE      MEAN ARGUMENT    STANDARD DEVIATION     SUM OF ARGUMENTS
FBTIM                 1490              161.34                324.50              240391.
     UPPER       OBSERVED       PERCENT      CUMULATIVE      CUMULATIVE     MULTIPLE      DEVIATION
     LIMIT       FREQUENCY      OF TOTAL     PERCENTAGE      REMAINDER      OF MEAN       FROM MEAN
        25            1            .06             .0            99.9           .15           -.42
        50           83           5.57            5.6            94.4           .31           -.34
        75          283          18.99           24.6            75.4           .46           -.26
       100          293          19.66           44.3            55.7           .62           -.18
       125          240          16.11           60.4            39.6           .77           -.11
       150          178          11.95           72.3            27.7           .93           -.03
       175          176          11.81           84.2            15.8          1.08            .04
       200          103           6.91           91.1             8.9          1.24            .11
       225           54           3.62           94.7             5.3          1.39            .19
       250           17           1.14           95.8             4.2          1.55            .27
       275            8            .53           96.4             3.6          1.70            .35
       300            6            .40           96.8             3.2          1.86            .42
       325            2            .13           96.9             3.1          2.01            .50
       375            1            .06           97.0             3.0          2.32            .65
       400            2            .13           97.1             2.9          2.48            .73
       425            1            .06           97.2             2.8          2.63            .81
       500            1            .06           97.2             2.8          3.10           1.04
       550            2            .13           97.4             2.6          3.41           1.20
OVERFLOW             39           2.62          100.0              .0
```

VOLUME (CU. FT. x 100) PER ACCUMULATOR HEAD LOAD

```
TABLE            ENTRIES IN TABLE      MEAN ARGUMENT    STANDARD DEVIATION     SUM OF ARGUMENTS
ACCVL                 1490             2075.66               1934.37             3092727.
     UPPER       OBSERVED       PERCENT      CUMULATIVE      CUMULATIVE     MULTIPLE      DEVIATION
     LIMIT       FREQUENCY      OF TOTAL     PERCENTAGE      REMAINDER      OF MEAN       FROM MEAN
       500          295          19.80           19.8            80.2           .24           -.81
      1000          274          18.39           38.2            61.8           .48           -.55
      1500          182          12.21           50.4            49.6           .72           -.29
      2000          157          10.54           60.9            39.1           .96           -.03
      2500          122           8.19           69.1            30.9          1.20            .21
      3000           92           6.17           75.3            24.7          1.45            .47
      3500           79           5.30           80.6            19.4          1.69            .73
      4000           58           3.89           84.5            15.5          1.93            .99
      4500           52           3.49           88.0            12.0          2.17           1.25
      5000           56           3.76           91.7             8.3          2.41           1.51
      5500           25           1.68           93.4             6.6          2.65           1.77
      6000           25           1.68           95.1             4.9          2.89           2.03
      6500           13            .87           96.0             4.0          3.13           2.29
      7000           17           1.14           97.1             2.9          3.37           2.55
      7500           13            .87           98.0             2.0          3.61           2.80
      8000            7            .47           98.5             1.5          3.85           3.06
      8500            4            .26           98.7             1.3          4.10           3.32
      9000           10            .67           99.4              .6          4.34           3.58
      9500            1            .06           99.5              .5          4.58           3.84
     10000            3            .20           99.7              .3          4.82           4.10
     11000            2            .13           99.8              .2          5.30           4.61
     11500            3            .20          100.0              .0          5.54           4.87
```

Figure 8.—*Simulation output.*

NUMBER OF TREES PER ACCUMULATOR HEAD LOAD

```
TABLE              ENTRIES IN TABLE        MEAN ARGUMENT      STANDARD DEVIATION      SUM OF ARGUMENTS
ACCTR                    1490                   2.54                  1.52                 3785.
        UPPER         OBSERVED        PERCENT       CUMULATIVE     CUMULATIVE      MULTIPLE      DEVIATION
        LIMIT         FREQUENCY       OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN      FROM MEAN
          1              537           36.04            36.0           64.0            .39          -1.02
          2              314           21.07            57.1           42.9            .78           -.35
          3              222           14.90            72.0           28.0           1.18            .30
          4              131            8.79            80.8           19.2           1.57            .96
          5              286           19.19           100.0             .0           1.97           1.62
```

NUMBER OF TREES PER SKIDDER BUNCH

```
TABLE              ENTRIES IN TABLE        MEAN ARGUMENT      STANDARD DEVIATION      SUM OF ARGUMENTS
BTRE                      348                  10.86                  3.57                 3779.
        UPPER         OBSERVED        PERCENT       CUMULATIVE     CUMULATIVE      MULTIPLE      DEVIATION
        LIMIT         FREQUENCY       OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN      FROM MEAN
          1                2             .57              .5           99.4            .09          -2.76
          3                3             .86             1.4           98.6            .27          -2.20
          4                8            2.30             3.7           96.3            .36          -1.92
          5               11            3.16             6.9           93.1            .46          -1.64
          6               16            4.60            11.5           88.5            .55          -1.36
          7               20            5.75            17.2           82.8            .64          -1.08
          8               26            7.47            24.7           75.3            .73           -.80
          9               33            9.48            34.2           65.8            .82           -.52
         10               40           11.49            45.7           54.3            .92           -.24
         11               43           12.36            58.0           42.0           1.01            .03
         12               41           11.78            69.8           30.2           1.11            .31
         13               32            9.20            79.0           21.0           1.20            .59
         14               20            5.75            84.8           15.2           1.29            .87
         15               19            5.46            90.2            9.8           1.38           1.16
         16                9            2.59            92.8            7.2           1.47           1.44
         17               12            3.45            96.3            3.7           1.57           1.72
         18                6            1.72            98.0            2.0           1.66           2.00
         19                4            1.15            99.1             .8           1.75           2.28
         20                1             .28            99.4             .5           1.84           2.56
         21                2             .57           100.0             .0           1.93           2.84
```

Figure 9.—*Simulation output.*

VOLUME (CU. FT. x 100) PER SKIDDER BUNCH

```
TABLE              ENTRIES IN TABLE        MEAN ARGUMENT      STANDARD DEVIATION      SUM OF ARGUMENTS
BVOL                      348               8877.64               4055.18               3089420.
        UPPER         OBSERVED        PERCENT       CUMULATIVE     CUMULATIVE      MULTIPLE      DEVIATION
        LIMIT         FREQUENCY       OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN      FROM MEAN
       1000                2             .57              .5           99.4            .11          -1.94
       2000                5            1.44             2.0           98.0            .22          -1.70
       3000               13            3.74             5.7           94.3            .33          -1.45
       4000               14            4.02             9.8           90.2            .45          -1.20
       5000               21            6.03            15.8           84.2            .56           -.95
       6000               32            9.20            25.0           75.0            .67           -.71
       7000               45           12.93            37.9           62.1            .78           -.46
       8000               33            9.48            47.4           52.6            .90           -.21
       9000               27            7.76            55.2           44.8           1.01            .03
      10000               32            9.20            64.4           35.6           1.13            .27
      11000               20            5.75            70.1           29.9           1.24            .52
      12000               31            8.91            79.0           21.0           1.35            .77
      13000               14            4.02            83.0           17.0           1.46           1.02
      14000               18            5.17            88.2           11.8           1.58           1.26
      15000               16            4.60            92.8            7.2           1.69           1.51
      16000                7            2.01            94.8            5.2           1.80           1.76
      17000                9            2.59            97.4            2.6           1.91           2.00
      18000                1             .28            97.7            2.3           2.03           2.25
      19000                2             .57            98.3            1.7           2.14           2.50
      20000                4            1.15            99.4             .5           2.25           2.74
      22000                1             .28            99.7             .2           2.48           3.24
      23000                1             .28           100.0             .0           2.59           3.48
```

Figure 10.—*Simulation output.*

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APPENDIX A

VARIABLE LISTS AND DEFINITIONS

DEFINITIONS

IMPLICIT TIME UNIT—CENTI-MINUTE

Model Segments, Transactions, and Parameters

Segment 1—TIMER
  Transactions—1 time keeper
  Parameters—None

Segment 2—FELLER/BUNCHER
  Transactions—Feller/buncher
  Parameters
    P1—not currently used
    P2—clock time marking cycle
    P3—current X coordinate of the feller/buncher
    P4—current Y coordinate of the feller/buncher
    P5—tree number being cut
    P6—X coordinate of the tree
    P7—Y coordinate of the tree
    P8—tree diameter
    P9—distance from feller/buncher to tree
    P10—end of strip indicator
    P11—sum of tree diameters in current accumulator load
    P12—volume of current accumulator load
    P13—number of trees in accumulator load

FUNCTIONS

DBH	Distribution of tree diameters in the stand
HYP	Distribution used to calculate the length of the hypotenuse of a right triangle
SNORM	Distribution used to obtain a normal distribution for sampling with a mean = 0, variance = 1, lower end truncated
YCDIF	Distribution of the distance along the strip from current tree to next tree; i.e., difference in Y coordinates
MCDLY	Distribution of the occurrence and duration of mechanical delay
NMDLY	Distribution of the occurrence and duration of nonmechanical delays

SAVEVALUES

ACCLM	Accumulator head limit of this load, number of trees
ACLM1	Accumulator head limit, maximum number of trees
ADLIM	Accumulator distance limit, maximum distance feller will travel to add another tree to load, feet
AVDBH	Mean stand diameter, inches × 100
AVHGT	Mean stand height, feet
AVVOL	Mean vol/acre, cu ft × 100

BDLIM	Bunch distance limit, maximum distance feller will travel to add trees to a partial skidder bunch, feet
BNCOM	Number of skidder bunches complete and ready for skidding
BNLM1	Maximum sum of diameter for skidder bunch size limit, inches
BRKTM	Total time spent on breaks, centi-minutes
BUNLM	Current bunch size limit—sum of diameter, inches
DAYS	Number of days worked
DELNM	Total time lost to nonmechanical delays, centi-minutes
DELYM	Total time lost to mechanical delay, centi-minutes
FBACC	Total number of feller/buncher accumulator loads
FBDIS	Total distance feller has traveled, feet
FBGPH	Feller/buncher fuel usage, gal/hr × 10
FBHR	Total time feller has worked, hours × 100
FBTIM	Total time feller has been on job, minutes × 100
FBTRE	Total trees cut
FBTYP	Feller/buncher type code, rubber-tired = 1
FBVOL	Total volume cut, cu ft × 100
FDRP1	Mean drop time, centi-minutes
FDRP2	Standard deviation drop time, centi-minutes
FSHR1	Mean shear time, centi-minutes
FSHR2	Standard deviation shear time, centi-minutes
FTRV1	Mean travel speed, ft/min
FTRV2	Standard deviation travel speed, ft/min
LBCFT	Density of stand species, lb/cu ft
MAX	Longest distance of travel (X or Y direction), ft
MIN	Shortest distance of travel (X or Y direction), ft
MVSTP	Distance feller travels between strips, ft
NUMFB	Number of feller/bunchers on job
PBDIA	Partial bunch sum of diameter, inches
PBEND	Partial bunch end of strip indicator
PBTRE	Partial bunch number of trees
PBVOL	Partial bunch—current volume, cu ft × 100
PBX	Partial bunch X coordinate
PBY	Partial bunch Y coordinate
STPLN	Length of strip, ft
STPWH	Width of strip, ft
STRIP	Number of strips harvested
TRPAC	Mean stand density, trees/acre
WKDAY	Length of work shift, hours
XDIF	Distance between the feller's current location and its next location across strip, ft
YDIF	Distance between the feller's current location and its next location along strip, ft

SWITCHES

COFFE	Set by timer to indicate coffee breaks
DAY	Set by timer to indicate beginning of workday
LUNCH	Set by timer to indicate lunch break

TABLES

ACCTR	Trees per accumulator load
ACCVL	Volume per accumulator load, cu ft × 100
BDIA	Sum of diameter of trees in skid bunch, inches
BTRE	Trees per skidder bunch
BVOL	Volume per skidder bunch, cu ft × 100
FBTIM	Cycle time for feller/buncher from drop to drop, including delays, centi-minutes

QUEUES

BREAK	Coffee and lunch break time
FBDRP	Swing and drop time
FBSHR	Position and shear time
FBTRV	All travel time
MCDLY	Mechanical delays
NMDLY	Nonmechanical delays

VARIABLES

ACCLM	Accumulator head limit, number of trees
BREAK	Time between breaks, centi-minutes
BRKTM	Time spent on breaks, centi-minutes
BUNLM	Skidder bunch limit, sum of diameter, inches
DELNM	Nonmechanical delay time, centi-minutes
DELYM	Mechanical delay time, centi-minutes
FBDRP	Swing and drop time, centi-minutes
FBHR	Total time, hours × 100
FBSHR	Shear time, centi-minutes
FBTRV	Travel time, centi-minutes
HYP	Length of hypotenuse of a right triangle
MCDLY	Length of mechanical delay
NEWY	Y coordinate when skidder changes strips
NIGHT	Remainder of 24 hours after work shift, centi-minutes

NMDLY	Length of nonmechanical delay, centiminutes
NXDIF	Used to make distance in X direction positive
NYDIF	Used to make distance in Y direction positive
RATIO	Ratio between the legs of a right triangle
SPEED	Feller buncher travel speed, ft/min
TDIAM	Tree diameter, inches
TVOL	Tree volume cu ft × 100
WKDAY	Length of work shift, centi-minutes
XCORD	X coordinate (across strip) of tree location, ft
YCORD	Y coordinate (down strip) of tree distance, ft
XDIF	X distance from feller buncher to tree
YDIF	Y distance from feller buncher to tree
XDIF1	X distance from feller buncher to partial bunch
YDIF1	Y distance from feller buncher to partial bunch

APPENDIX B

PROGRAM LISTING

```
     /. . . . . . . . . . . . . . . . . . . . . . . . . . .
     *
     *         FELLER BUNCHER SIMULATOR
     *             UPDATED  JAN 1981
     *
     *
     *       U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
     *       MARRKETING PROJECT, DULUTH, MINNESOTA
     *       ENGINEERING PROJECT, HOUGHTON, MICHIGAN
     *
     *         AUTHORS:  SHARON A. WINSAUER
     *                   DENNIS P. BRADLEY
     *
     *  . . . . . . . . . . . . . . . . . . . . . . . . . .
     *
     *
     *  . . . . . . . . . . . . . . . . . . . . . . . . . .
     *
     *                MASTER TIMER AND REPORT GENERATOR
     *
     *  . . . . . . . . . . . . . . . . . . . . . . . . . .
     *
     *         THIS SEGMENT CONTROLS THE STOP AND START OF THE FELLER BUNCHER,
     *           THE HOURS WORKED  PER DAY, X$WKDAY, AND THE NUMBER OF
     *           DAYS WORKED(ARGUMENT A ON START CARD)
     *
     *         IT ALSO CALCULATES OUTPUT VALUES,VALUES TO BE SENT TO HELP BLOCKS,
     *
     *
     *
      WKDAY VARIABLE    X$WKDAY*6000           WORKDAY IN CENTIMINUTES
      BREAK FVARIABLE   V$WKDAY/4              TIME BETWEEN BREAKS
      NIGHT VARIABLE    (24-X$WKDAY)*6000      REST OF 24 HOURS IN CENTIMINUTES
     *
  1   TIMER GENERATE    ,,,1,12
  2   NXDAY SAVEVALUE   DAYS+,1                NUMBER OF CURRENT WORKING DAY
  3         LOGIC S     DAY
  4   DAY   ADVANCE     V$BREAK                TIME FOR COFFEE BREAK
  5         LOGIC S     COFFE
  6         ADVANCE     V$BREAK                WORK UNTIL LUNCH TIME
  7         LOGIC S     LUNCH
  8         ADVANCE     V$BREAK                AFTERNOON COFFEE
  9         LOGIC S     COFFE
 10         ADVANCE     V$BREAK                END OF WORK DAY
 11         LOGIC R     DAY
 12         ADVANCE     V$NIGHT                WAIT UNTIL NEXT MORNING
     *
     *
     * * * *  HELP BLOCKS  GENERATE REPORT AT END OF EACH DAY
     *
     *
     * * * * REPORT VARIABLES
     *
 13         SAVEVALUE   FBHR,V$FBHR            HOURS FB HAVE WORKED
 14         SAVEVALUE   BRKTM,V$BRKTM          TIME FB SPENT ON BREAKS IN MIN*100
 15         SAVEVALUE   DELYM,V$DELYM          MECHANICAL DELAY TIME OF FB
 16         SAVEVALUE   DELNM,V$DELNM          NON-MECHANICAL DELAY TIME OF FB
      FBHR  FVARIABLE   X$FBTIM/60
      BRKTM FVARIABLE   QT$BREAK*QC$BREAK
      DELYM FVARIABLE   QT$MCDLY*QC$MCDLY
      DELNM FVARIABLE   QT$NMDLY*QC$NMDLY
     * * * * STAND DATA AND MACHINE CHARACTERISTICS REPORT
     *
17         HELP        SYSTM,X$AVVOL,X$AVDBH,X$AVHGT,X$TRPAC
18         HELP        SYSTM,X$NUMFB,X$ACLM1,X$FBTYP,X$BNLM1
     *                AVE VOL,AVE DBH,AVE HEIGHT,TREES/ACRE,NUM OF FELLERS
     *           FB ACCUMULATOR HEAD LIMIT,FB TYPE,SKIDDER BUNCH LIMIT
     *
     * * * * FELLER BUNCHER  PRODUCTION REPORT
     *
19         HELP        FELBN,X$NUMFB,X$FBTYP,X$BRKTM,X$DELYM,X$DELNM
     *        NUM OF FELLER BUNCHERS, FB TYPE,BREAKTIME,DELAY TIME
     *
20         HELP        FELBN,X$FBTRE,X$FBVOL,X$BNCOM,X$FBHR,X$FBDIS
     *        TOT TREES,TOT VOL,SKID BUNCHES COMPLETED,FB HOURS,TOT DIST TRAVELED
     *
21         HELP        FELBN,X$FBACC,X$LBCFT,X$FBVOL,X$FBGPH
     *        NUM OF ACC LOADS, WOOD DENSITY LB/CUFT, TOT VOL, GAL PER HOUR USED
     *
22         SPLIT       1,NXDAY
23   OUTPT TERMINATE   1
     *
     * - - - - - - - - - - - - - - - - - - - - - - - - - - -
     *
     *     GENERAL FUNCTIONS NEEDED IN MODEL
     *
     * - - - - - - - - - - - - - - - - - - - - - - - - - - -
     *
     * * * * FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
     *         NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
     *
     *      NOTE: TO AVOID DATA LOSS FROM INTERGERAZATION,
     *            FUNCTION VALUES HAVE BEEN
     *            MULTIPLIED BY 10
     *         * * USE    MEAN+(FN$SNORM * S.DEV)/10
     *
     *      NOTE: LOWER END OF FUNCTION HAS BEEN TRUNCATED
     *             TO AVOID NEGATIVE ADVANCE BLOCKS
     *              WHEN STANDARD DEVIATIONS ARE LARGE
     *
     *
     SNORM FUNCTION    RN2,C20
     0,-15/.0668,-15/.1151,-12/.1587,-10/.2119,-8/.2742,-6/.3446,-4
     .4207,-2/.5,0/.5793,2/.6544,4/.7258,6/.7881,8/.8413,10/.8849,12
     .9332,15/.9772,20/.9938,25/.9986,30/.9999,40/1.,50
     *
     *
     *      THIS FUNCTION IS USED FOR DISTANCE? FOR THE FELLER BUNCHER
     *
     * * * * VSHYP GIVES THE LENGTH OF THE HYPOTENUSE OF A RT TRIANGLE
     *         WITH SIDES EQUAL TO X$MAX AND X$MIN
     *
     RATIO VARIABLE    X$MAX*10/X$MIN
     *
     HYP   VARIABLE    X$MAX*FN$HYP/1000
     *
     HYP   FUNCTION    V$RATIO,D24
     10,1414/11,1351/12,1302/13,1262/14,1229/15,1202/16,1179/17,1160/18,1144
     19,1130/20,1118/22,1098/24,1083/26,1071/28,1062/30,1054/35,1040/40,1031
     50,1020/60,1014/70,1010/80,1008/100,1005/20000,1000
     *
     *
     *
```

```
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
* * * *  ACCUMULATING OR SINGLE STEM RUBBER TIRED FELLER BUNCHER SEGMENT
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*
*        THIS SEGMENT MODELS A RUBBER-TIRED FELLER BUNCHER WITH
*        AN ACCUMULATING SHEAR ATTACHED TO THE FRONT
*
*        THE FELLER TRAVELS FROM TREE TO TREE, CUTTING EACH
*        TREE, GENERALLY CUTTING A REASONABLY WIDE
*        SWATH OR STRIP THROUGH THE WOOD
*
*        THE FELLER COMBINES MULTIPLE ACCUMULATOR HEAD
*        BUNCHES TO OBTAIN BUNCHES LARGE ENOUGH FOR
*        THE SKIDDER.
*
*
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*                   FELLER BUNCHER PARAMATER ASSIGNMENTS
*
*            P1     NOT USED
*            P2     CLOCK TIME
*            P3     X COORD OF FELLER BUNCHER
*            P4     Y COORD OF FELLER BUNCHER
*            P5     TREE NUMBER
*            P6     X COORD OF TREE
*            P7     Y COORD OF TREE
*            P8     TREE DIAMETER
*            P9     DIST FROM FB TO TREE
*            P10    END OF STRIP INDICATOR
*            P11    SUM OF DIAMETER OF LOAD
*            P12    SUM OF VOLUME OF LOAD
*            P13    NUMBER OF TREES IN LOAD
*
* * *    DEFINING VARIABLES FOR FELLER BUNCHER
*
*
NEWY   VARIABLE    P7-X$STPLN              NEW Y CORD AT BEGINNING OF STRIP
XDIF   VARIABLE    P6-P3                   X DIST FB TO TREE
YDIF   VARIABLE    P7-P4                   Y DIST FB TO TREE
XDIF1  VARIABLE    X$PBX-P3                X DIST FB TO PARTIAL BUNCH
YDIF1  VARIABLE    X$PBY-P4                Y DIST FB TO PARTIAL BUNCH
NXDIF  VARIABLE    -X$XDIF                 USED TO CONVERT SIGNED
NYDIF  VARIABLE    -X$YDIF                      DISTANCE TO MAGNITUDES
*
*
* * *  OUTPUT TABLES FOR FELLER BUNCHER
FBTIM  TABLE       MP2,0,25,25             OUTPUT TABLES FOR FB
ACCVL  TABLE       P12,0,500,25            CYCLES
ACCTR  TABLE       P13,0,1,12
*
BDIA   TABLE       P11,0,5,30              TABLES OF SKIDDER BUNCHES
BTRE   TABLE       P13,0,1,25              CREATED
BVOL   TABLE       P12,0,1000,25
```

```
     * * * *  GENERATE FELLER BUNCHER, INITIALIZE ACC HEAD
     *                AND ASSIGN ACCUMULATOR AND BUNCH SIZE LIMITS
     *
24   ACCFB GENERATE   ,,,1,10,15
     *
25   INIT  ASSIGN     11,0                INITILIZE ACCUMULATOR HEAD
26         ASSIGN     12,0
27         ASSIGN     13,0
28         MARK       2                   MARK START OF CYCLE
29         SAVEVALUE  ACCLM,V$ACCLM       MAXIMUM ACC LOAD
30         SAVEVALUE  BUNLM,V$BUNLM       MAXIMUM BUNCH SIZE
     *
     *
     *
     * * * TREE    CREATE NEXT TREE
     *
31   TREE  ASSIGN     5+,1                TREE NUMBER
32         ASSIGN     6,V$XCORD           X COORDINATE OF TREE
33         ASSIGN     7,V$YCORD           Y COORDINATE OF TREE
34         ASSIGN     8,V$TDIAM           DBH OF TREE
     *
     *
     *
     * * * *  ? IS TREE IN A NEW STRIP ?   IF NOT GO TO OLDST
     *                 IF A NEW STRIP - REASSIGN Y CORD AND MARK END OF
     *                 STRIP P10
     *
35         TEST G     P7,X$STPLN,OLDST          ? NEW STRIP ?
36         ASSIGN     7,V$NEWY            NEW Y COORD
37         ASSIGN     10,1                END OF STRIP INDICATOR
38         TRANSFER   ,ACCFL
     *
     *
     *
     * * * * OLDSTP - THE FB DID NOT MOVE TO A NEW STRIP.  SEE IF THERE IS
     *                ROOM IN ACC HEAD FOR ANOTHER TREE - IF SO SEE HOW FAR
     *                AWAY TREE IS.
     *
39   OLDST TEST L     P13,X$ACCLM,ACCFL      IF ACCHEAD FULL - GO TO ACCFL
     *
40   TDIST SAVEVALUE  XDIF,V$XDIF         CALCULATE DISTANCE TO TREE
41         TEST L     X$XDIF,0,DTST1
42         SAVEVALUE  XDIF,V$NXDIF
43   DTST1 SAVEVALUE  YDIF,V$YDIF
44         TEST L     X$YDIF,0,DTST2
45         SAVEVALUE  YDIF,V$NYDIF
46   DTST2 SAVEVALUE  MAX,X$XDIF
47         SAVEVALUE  MIN,X$YDIF
48         TEST L     X$MAX,X$MIN,DTST3
49         SAVEVALUE  MIN,X$XDIF
50         SAVEVALUE  MAX,X$YDIF
51   DTST3 ASSIGN     9,X$MAX
52         TEST G     X$MIN,0,FIRST
53         ASSIGN     9,V$HYP             DIST FROM FB TO TREE
     *
```

```
   * * * *  FIRST  IF THIS IS THE FIRST TREE IN THE ACCUMULATOR
   *                GO TO FELL AND FELL THE TREE.     IF IT IS NOT
   *                THE FIRST TREE SEE HOW FAR AWAY THE TREE IS.
   *                IF TOO FAR GO TO ACCFL - THIS IS A COMPLETE LOAD
   *
54  FIRST TEST G     P11,0,FELL     ? IF FIRST TREE ?
55        TEST L     P9,XSADLIM,ACCFL ? TREE TOO FAR?
   *
   *
   * * * *  FELL       FELLER BUNCHER TRAVELS TO TREE AND FELLS IT
   *               ADDS TREE TO ACCUMULATOR HEAD AND RECORDS PRODUCTION
   *                DATA, THEN FB LOOKS AT NEXT TREE
   *
56  FELL  QUEUE      FBTRV
57        ADVANCE    VSFBTRV            FELLER TRAVELS TO TREE
58        DEPART     FBTRV
59        ASSIGN     4,P7               TREE COORDINATES BECOME
60        ASSIGN     3,P6               FB COORDIANATES
61        QUEUE      FBSHR
62        ADVANCE    VSFBSHR            FB SHEARS TREE
63        DEPART     FBSHR
   *
   *                                    FB ADDS TREE TO ACC HEAD
64        ASSIGN     11+,P8             SUM OF DIA
65        ASSIGN     13+,1              NO OF TREES
66        ASSIGN     12+,V$TVOL         TOTAL LOAD VOL
   *
67        SAVEVALUE  FBTRE+,1           RECORD PRODUCTION OF FELLER
68        SAVEVALUE  FBVOL+,V$TVOL
69        SAVEVALUE  FBDIS+,P9
70        TRANSFER   ,TREE
   *
   *
   * * * *  ACCFL  - ACCUMULATOR FULL
   *                ? HAS A PARTIAL BUNCH BEEN STARTED ?
   *                IF NO PARTIAL BUNCH GO TO DROP-DROP TREES AT CURRENT LOCATION.
   *                IF THERE IS A PARTIAL BUNCH SEE HOW FAR AWAY IT IS
   *
71  ACCFL TEST G     X$PBDIA,0,DROP     HAS A PARTIAL BUNCH BEEN STARTED?
   *                                    IF NOT - GO TO DROP
72        SAVEVALUE  XDIF,V$XDIF1       CALCULATE DISTANCE FROM FB
73        TEST L     X$XDIF,0,DTSTA     TO PARTIAL BUNCH
74        SAVEVALUE  XDIF,V$NXDIF
75  DTSTA SAVEVALUE  YDIF,V$YDIF1
76        TEST L     X$YDIF,0,DTSTB
77        SAVEVALUE  YDIF,V$NYDIF
78  DTSTB SAVEVALUE  MAX,X$XDIF
79        SAVEVALUE  MIN,X$YDIF
80        TEST L     X$MAX,X$MIN,DTSTC
81        SAVEVALUE  MAX,X$YDIF
82        SAVEVALUE  MIN,X$XDIF
83  DTSTC ASSIGN     9,X$MAX
84        TEST G     X$MIN,0,PBFAR
85        ASSIGN     9,V$HYP                 DISTANCE FB TO PARTIAL BUNCH
   *
   *
   * * * *  PBFAR  PARTIAL BUNCH TOO FAR?
   *                IF P BUNCH IS NOT TOO FAR AWAY TRAVEL TO  PARTIAL
   *                BUNCH-TRVPB AND DROP LOAD, IF IT IS TOO FAR
   *                START NEW BUNCH RIGHT HERE, SEND AN OFFSPRING OF SPLIT BLOCK
   *                OVER TO MAKE LAST PARTIAL BUNCH COMPLETE
```

```
 86   PBFAR TEST G     P9,XSBDLIM,TRVPB  IS PARTIAL BUNCH TOO FAR ?
     *
 87         PRIORITY   16
 88         SPLIT      1,BUNCH          OFFSPRING GOES TO MAKE LAST BUNCH
 89         PRIORITY   10               COMPLETE WHILE FB DROPS TREES
 90         BUFFER                      HERE AND STARTS NEW BUNCH
 91         TRANSFER   ,DROP
     *
     *
     *
     * * * * TRVPB - TRAVEL TO PARTIAL BUNCH
     *
 92   TRVPB QUEUE      FBTRV
 93         ADVANCE    V$FBTRV          FB TRAVELS TO PART BUNCH
 94         DEPART     FBTRV
 95         ASSIGN     3,X$PBX          PB COORDINATES BECOME FB COORDINATES
 96         ASSIGN     4,X$PBY
 97         SAVEVALUE  FBDIS+,P9
     *
     * * * * DROP -   FELLER DROPS TREES IN ACC HEAD
     *                 EITHER ADDING TO EXISTING PARTIAL BUNCH OR
     *                 STARTING A NEW BUNCH
     *
 98   DROP  QUEUE      FBDRP
 99         ADVANCE    V$FBDRP          DROP TREES FROM ACC HEAD
100         DEPART     FBDRP
101         SAVEVALUE  PBDIA+,P11       TOTAL SUM OF DIAM IN BUNCH
102         SAVEVALUE  PBTRE+,P13       TOTAL NUMBER OF TREES
103         SAVEVALUE  PBEND,P10        STRIP END INDICATOR
104         SAVEVALUE  PBVOL+,P12       TOTAL VOL
105         SAVEVALUE  PBX,P3           X COORD OF BUNCH
106         SAVEVALUE  PBY,P4           Y COORD OF BUNCH
     *
     * * *  DELAY    IF A DELAY IS TO OCCUR IT HAPPENS HERE
107         QUEUE      MCDLY
108         ADVANCE    V$MCDLY          MECHANICAL DELAY
109         DEPART     MCDLY
110         QUEUE      NMDLY
111         ADVANCE    V$NMDLY          NONMECHANICAL DELAY
112         DEPART     NMDLY
     * * *                   CHECK IF TIME FOR BREAK
113         QUEUE      BREAK
114         GATE LS    COFFE,NOBRK      CHECK IF BREAK TIME
115         ADVANCE    1500             15 MIN COFFEE BREAK
116         LOGIC R    COFFE
117   NOBRK GATE LS    LUNCH,QUIT       CHECK IF LUNCH TIME
118         ADVANCE    3000
119         LOGIC R    LUNCH
```

```
          * * *  QUIT - TABULATE TIME ON BREAKS AND CHECK IF ITS TIME TO QUIT
          *
 120       QUIT  SAVEVALUE  FBTIM+,MP2        TABULATE CYCLE TIME
 121             DEPART     BREAK
          *
 122             SAVEVALUE  FBACC+,1          KEEP TRACK OF NUMBER OF ACC LOADS
 123             TABULATE   FBTIM             TABULATE TIME AND PRODUCTION
 124             TABULATE   ACCVL
 125             TABULATE   ACCTR
 126             GATE LS    DAY               IF SHIFT IS OVER, STOP TIL TOMORROW
          *                                   REINITILIZE ACC HEAD
 127             MARK       2                 MARK START OF CYCLE
 128             ASSIGN     11,0
 129             ASSIGN     12,0
 130             ASSIGN     13,0
 131             ASSIGN     10,0
 132             MARK       2
 133             SAVEVALUE  ACCLM,V$ACCLM     SET NEW ACC HEAD LIMIT
          *
          *
          * * * *  ? IS THIS A COMPLETE BUNCH OR THE END OF A STRIP ?
          *                 IF SO GO TO BNCOM TO COLLECT BUNCH DATA
          *                 IF NOT A COMPLETE BUNCH
          *                 OR THE END OF A STRIP - GO BACK TO FELL NEXT TREE
          *
 134             TEST L     X$PBDIA,X$BUNLM,BNCOM  IS BUNCH COMPLETE ?
 135             TEST G     X$PBEND,0,TDIST        IS IT THE END OF A STRIP ?
          *
          *
          *
          * * * * BNCOM - BUNCH COMPLETE  OFFSPRING GOES TO COMPLETE
          *                 BUNCH WHILE PARENT -FELLER BUNCHER- GOES TO CUT NEXT TREE
          *
 136       BNCOM PRIORITY   16
 137             SPLIT      1,BUNCH
 138             PRIORITY   10
 139             BUFFER
 140             TEST GE    X$PBEND,1,TDIST   IF END OF STRIP
 141             ASSIGN     4,P7              CORRECT DISTANCE TO NEW STRIP
 142             ASSIGN     3,P6
 143             ASSIGN     3+,X$MVSTP        ADD DISTANCE BETWEEN STRIPS
 144             TRANSFER   ,TDIST
          *
          * * * *  BUNCH -  BUNCH IS DESIGNATED COMPLETE AND READY
          *                  FOR SKIDDER TO PICK UP
          *
          *                 BUNCH IS CONSIDERED COMPLETE WHEN IT IS BIG
          *                  ENOUGH FOR THE SKIDDER, OR IF P BUNCH IS TOO FAR
          *                  FROM FELLER BUNCHER,OR FELLER BUNCHER HAS
          *                  REACHED THE END OF A STRIP
          *
     145   BUNCH SAVEVALUE  BNCOM+,1
          *                                  MAKE P BUNCH XTION INTO ACTIVE XTION
     146         ASSIGN     12,X$PBVOL       VOLUME OF BUNCH
     147         ASSIGN     11,X$PBDIA       SUM OF DIAM
     148         ASSIGN     13,X$PBTRE       TOTAL NUM OF TREES
     149         ASSIGN     4,X$PBY          Y COORD DOWN STRIP
          *
     150         SAVEVALUE  PBDIA,0          REINITIALIZE PARTIAL BUNCH
     151         SAVEVALUE  PBTRE,0
     152         SAVEVALUE  PBVOL,0
     153         SAVEVALUE  BUNLM,V$BUNLM    SET BUNCH LIMIT
          *
          *                                  RECORD BUNCH PRODUCTION
     154         TABULATE   BDIA
     155         TABULATE   BTRE
     156         TABULATE   BVOL
     157         TERMINATE
          * * * * * * INPUT DATA
          *
          *
           FBTRV FVARIABLE  P9*100/V$SPEED          TRAVEL TIME (DIST/SPEED) IN CENTIMIN
          *                                         P9 = DISTANCE
           SPEED FVARIABLE  X$FTRV1+X$FTRV2*FN$SNORM/10      TRAVEL SPEED
           FBSHR FVARIABLE  X$FSHR1+X$FSHR2*FN$SNORM/10      POSITION AND SHEAR TIME
           FBDRP FVARIABLE  X$FDRP1+X$FDRP2*FN$SNORM/10      SWING AND DROP TIME
          *
           ACCLM FVARIABLE  X$ACLM1                          MAX ACC LOAD  NUM OF TREES
           BUNLM FVARIABLE  X$BNLM1                          MAX BUNCH SIZE - SUM OF DIA
          *
           XCORD FVARIABLE  (X$STPWH+1)*RN3/1000    X COORDINATE OF TREE
           YCORD FVARIABLE  FN$YCDIF+P7             Y COORDINATE OF TREE
           TDIAM FVARIABLE  FN$DBH                  DIAMETER OF TREE
           TVOL  FVARIABLE  (186*P8*P8-283)/10      TREE VOL IN TERM OF DIA(P8)
          *                                         .01 CU FT
           MCDLY FVARIABLE  FN$MCDLY                MECHANICAL DELAY
           NMDLY FVARIABLE  FN$NMDLY                NON-MECHANICAL DELAY
          *
```

```
* * * * *  DEFINING FUNCTIONS
*
*      THIS INPUT DATA WAS OBTAINED FROM TIMF STUDIES CARRIED OUT IN 1974
*
 YCDIF FUNCTION   RN3,D10                 YDIST FROM CURRENT TREE TO NEXT TREE
.18,0/.48,2/.64,4/.76,6/.84,8/.88,10/.92,12/.95,14/.98,16/1.,18
*
*
 DBH   FUNCTION   RN4,C11                 DIAMETER DISTRIBUTION
0,2/.254,4/.497,6/.783,8/.869,10/.932,12/.964,14/.984,16/.995,18/.999,20
1.0,22
*
 NMDLY FUNCTION   RN6,C8                  NON-MECHANICAL DELAY
0,0/.973,0/.982,100/.987,200/.992,500/.996,1000/.999,2000/1.0,5000
*
 MCDLY FUNCTION   RN6,C5                  MECHANICAL DELAY
0,0/.994,0/.996,500/.998,1000/1.0,5000
*
* * * * * *  INITIAL CONDITIONS FOR THE STAND
*
       INITIAL    X$AVDBH,510             AVE STAND DBH (IN*100)
       INITIAL    X$AVVOL,284200          STAND VOL (.01 CU FT/ACRE)
       INITIAL    X$AVHGT,60              AVE TREE HEIGHT (FT)
       INITIAL    X$TRPAC,550             TREES/ACRE
       INITIAL    X$STPLN,660             STRIP LENGTH (FT)
       INITIAL    X$STPWH,10              STRIP WIDTH (FT)
       INITIAL    X$MVSTP,32              DISTANCE BETWEEN STRIPS (FT)
       INITIAL    X$LBCFT,55              WOOD DENSITY LB/CU FT - GREEN
       INITIAL    X$WKDAY,8               HOURS IN A WORK SHIFT
*
* * * * * *  INITIAL CONDITIONS FOR THE RUBBER TIRED FELLER/BUNCHER
*
       INITIAL    X$ADLIM,8               ACCUMULATOR DISTANCE LIMIT
       INITIAL    X$BDLIM,45              BUNCH DISTANCE LIMIT
       INITIAL    X$FBGPH,47              FUEL CONSUMPTION (GAL PER HR * 10)
       INITIAL    X$FTRV1,150             MEAN TRAVEL SPEED (FT/MIN)
       INITIAL    X$FTRV2,50              ST. DEV. TRAVEL SPEED (FT/MIN)
*
       INITIAL    X$FSHR1,25              MEAN SHEAR TIME (CENT MINUTES)
       INITIAL    X$FSHR2,12              ST. DEV. SHEAR TIME
       INITIAL    X$FDRP1,15              MEAN DROP TIME (CENT MINUTES)
       INITIAL    X$FDRP2,9               ST. DEV. DROP TIME
       INITIAL    X$ACLM1,5               MAXIMUM * TREES IN ACC HEAD
*
       INITIAL    X$BNLM1,120             MAX SKIDDER BUNCH -SUM OF DIA (IN)
       INITIAL    X$FBTYP,1               RUBBER TIRED FELLER BUNCHER CODE
* * * * * *  INITIAL CONDITIONS FOR THE RUN
       RMULT      4,83,151,,701
       START      5,,5,1
       END
```

```
          SUBROUTINE SYSTM(IX)
          DIMENSION IX(5)
          DATA I/0/
C
      1 FORMAT(1H1,43X,'FULL  TREE  FIELD  CHIPPING  ',
       A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
       B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
       CT.  OF  AGRICULTURE'//1H0,29X, 'FOREST  PRODUCTS  MARKETING  AND
       TUTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H ,
       E40X,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H0,62X
       F,'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
       G A. WINSAUER, PROGRAMMER'//)
C
      2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.'//1H0, F12.2,' CU FT. ',
       A  'AVERAGE VOLUME',
       B' PER ACRE.'/1H0,F12.2,' INCHES, AVERAGE DBH.'/1H0,F12.2,' FEET,',
       C' AVERAGE TREE HEIGHT.'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
       D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
C
      3 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
       A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X ,I10,'  MACHINE',
       B  5X,'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'
       C  , //9X,'MACHINE LIMITATIONS '/)
C
      4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
       A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X ,I10,'  MACHINE',
       B5X,'RUBBER-TIRED TYPE',//,9X,'MACHINE LIMITATIONS. '/)
C
      5 FORMAT(1H , 14X, 'THE SHEAR CAN HANDLE ONLY ONE TREE.')
C
      6 FORMAT( 1H , 10X, 'THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN',
       A ' A LOAD OF UP TO',F6.1,' TREES')
C
      7 FORMAT(1H0,8X,'BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:'/
       A1H0, 10X,'THE FELLER-BUNCHERS TRY TO ACHIEVE'    ,
       B ' SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO',
       C F6.1, ' INCHES')
C
C
          X1 = IX(1)
          X2 = IX(2)
          X3 = IX(3)
          X4 = IX(4)
          X5 = IX(5)
          I = I + 1
          IF ( I .GT. 2 ) I = 1
          GO TO (10,20),I
C
     10 CONTINUE
          AVVOL= X1/100.
C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
          AVDBH= X2/100.
C ACDBH = AVERAGE DBH - INCHES
          AVHGT=X3
C AVHGT = AVERAGE TREE HEIGTH - FEET
          TRPAC=X4
C TRPAC = AVERAGE NUMBER TREES PER ACRE
          TRSPC=(43560./TRPAC)**.5
C TRSPC = AVERAGE TREE SPACING - FEET
          WRITE (6,1)
          WRITE(6,2) AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
          RETURN
C
     20 CONTINUE
          NUMFB=1
C NUMFB = NUMBER OF FELLER-BUNCHERS
          ACCLM =  X2
C ACCLM ACCUMULATOR LIMIT SUM OF DBH
          FBTYP=X3
C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
          BUNLM = X4
C  BUNLM  BUNCH SIZE LIMIT
          IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
          IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
          IF (ACCLM .LT. 1.) WRITE(6,5)
          IF (ACCLM .GE. 1.) WRITE(6,6) ACCLM
          WRITE(6,7) BUNLM
          RETURN
C
          END
      SUBROUTINE FELBN (IX)
      DIMENSION IX(5)
      DATA I/0/
      INTEGER FBACC,FBDIS,BNCOM
C
    1 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',//,1H ,132('*'),////
     B//,1H,'I.     A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER(S)'
     1 ,' INCLUDING'//16X,F8.2,
     2 5X        'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3    5X,    'MINUTES MECHANICAL DELAY, ',/  / 16X,F8.2,
     4 5X,       'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER.',5X,
     D 'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'///)
C
    2 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',//,1H ,132('*'),////
     B//,1H,'I.     A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER'
     1 ,' INCLUDING'//16X,F8.2,
     2 5X,       'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3    5X,    'MINUTES MECHANICAL DELAY, ',/  / 16X, F8.2,
     4 5X,       'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER.',5X,
     D'RUBBER-TIRED TYPE.'////)
C
    3 FORMAT(1H,'II.    A.',I8,5X,'TOTAL ACCUMULATOR CYCLES COMPLETED',
     A' - ALL MACHINES.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' CYCLE.',//,16X,F8.2,5X,'AVERAGE VOLUME PER CYCLE - CU.FT.',/)
C
    4 FORMAT(1H,6X,'B.',I8,5X,'BUNCHES COMPLETED',//,
     A16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER BUNCH.',/)
C
    5 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF CYCLES PER BUNCH.',/)
C
    6 FORMAT(1H,15X,F8.2,5X,'AVERAGE VOLUME PER BUNCH - CU.FT.',//,
     A7X,'C.',I8,5X,'TOTAL TREES FELLED.',//,7X,'D.',F8.1,5X,
     B'TOTAL VOLUME FELLED - CU.FT.',//,7X,'E.',
     CF8.2,5X,'TOTAL TONS FELLED',//,7X,'F.',I8,5X,
     D   'TOTAL DISTANCE TRAVELED - FEET',///)
C
    7 FORMAT(1H,'III.   A.',F8.2,5X,'AVERAGE NUMBER OF CYCLES PER',
     A' MACHINE HOUR.',/)
C
    8 FORMAT(1H,6X,'B.',F8.2,5X,'AVERAGE NUMBER OF BUNCHES COMPLETED',
     A' PER MACHINE HOUR.',//,7X,'C.',F8.2,5X,'AVERAGE NUMBER OF',
     B' TREES FELLED PER MACHINE HOUR.',//,7X,'D.',F8.2,5X,'AVERAGE',
     C' VOLUME FELLED PER MACHINE HOUR.',//,7X,'E.',F8.2,5X,'AVERAGE',
     D' NUMBER OF TONS FELLED PER MACHINE HOUR.',//,7X,'F.',F8.2,5X,
     E'AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.',///)
C
C
   11 FORMAT(1H,'IV.    A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED BY',
     A' THE FELLER-BUNCHER.',//,16X,F8.2,5X,'GALLONS PER HOUR.',//,16
     BX,F8.2,5X,'GALLONS PER TON.',//,16X,F8.2,5X,'GALLONS PER CUNIT.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I+ 1
      IF (I .GT. 3 ) I = 1
      GO TO ( 10,20,30),I
   10 CONTINUE
      NUMFB = 1
C NUMFB =  NUMB. OF FELLER-BUNCHERS
      FBTYP = X2
C   FELLER-BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
C   BREAK AND DELAY TIMES IN MINUTES
      BREAK=X3/100
      DELAY=X4/100
      DELNM=X5/100
      RETURN
   20 CONTINUE
```

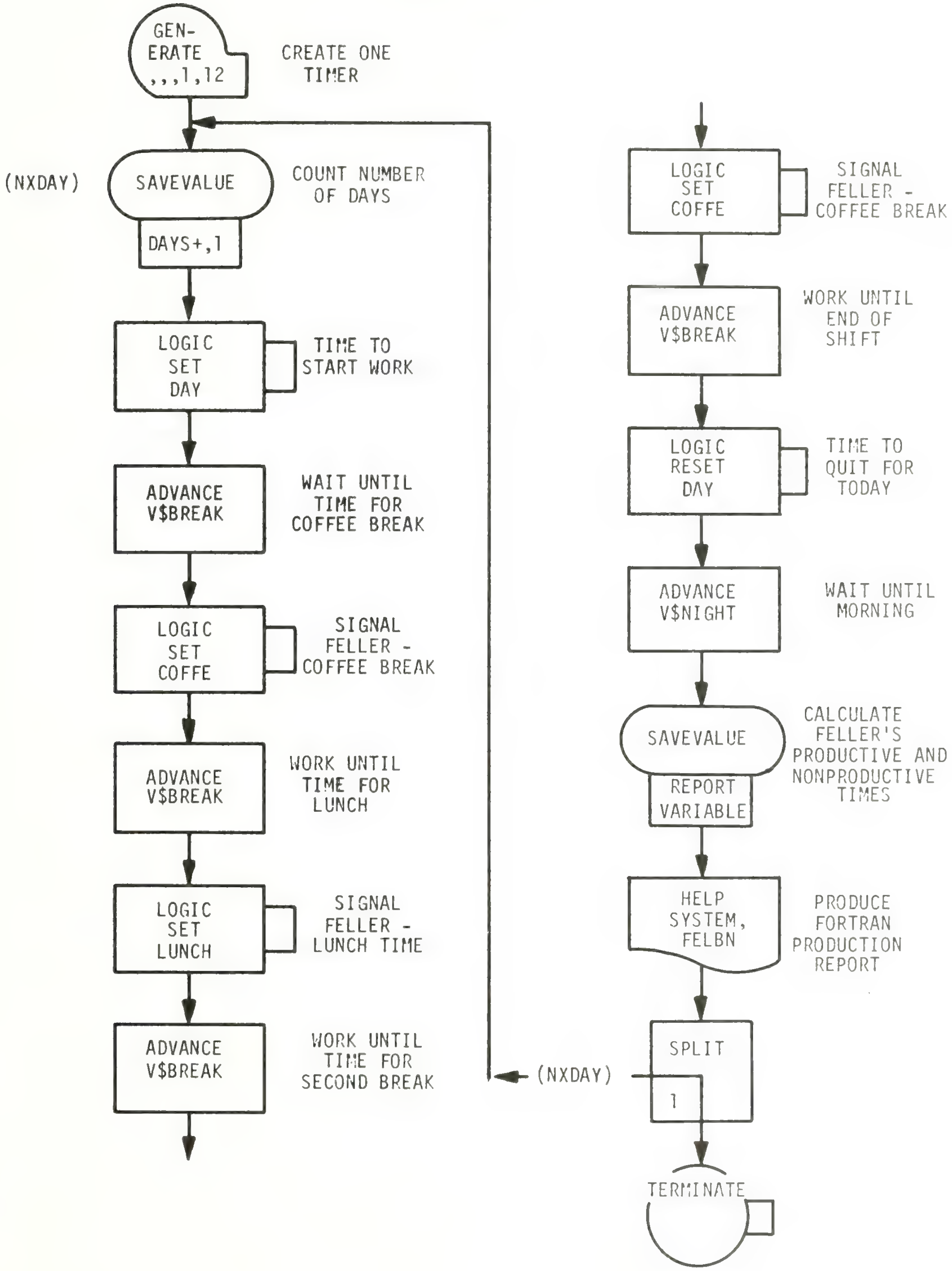
```
      NTREE =  X1
      FBVOL = X2/100.
C FBVOL =    VOL. FELLED ALL MACHINES
      FBCNT = FBVOL/100.
C  FBCNT  FELLER-BUNCHER VOL. IN CUNITS.
      BNCOM = X3
C BNCOM =  BUNCHES COMPLETED
      FBHR = X4/100.
      FBDIS =  X5
C FBDIS =   DIST. TRAV. ALL MACHINES
      RETURN
   30 CONTINUE
      FBACC = X1
C  FBACC  NUMBER OF ACCUMULATOR COMPLETED CYCLES.
      XDEN = X2
C  POUNDS OF WOOD PER CUBIC FOOT.
      FBTNS = X3*XDEN/200000
      FBGPH = X4/10
C  FELLER-BUNCHER TOTAL GALLONS USED
C  FELLER-BUNCHER VOL. IN TONS
C
      IF( FBTYP.EQ.0 )WRITE(6,1)FBHR,BREAK,DELAY,DELNM,NUMFB
      IF( FBTYP.EQ.1 )WRITF(6,2)FBHR,BREAK,DELAY,DELNM,NUMFB
C
      FBTPC = NTREE*1./FBACC
C  FBTPC  TREES PER CYCLE
      FBVPC = FBVOL/FBACC
C  FBVPC  VOLUME PER CYCLE
      WRITE(6,3)FBACC,FBTPC,FBVPC
C
      FBTPB =  NTREE*1./BNCOM
C FBTPB =  AVE. TREES PER COMPLETED BUNCH.
      WRITE(6,4)BNCOM,FBTPB
C
      FBCPB = FBACC*1./BNCOM
      WRITE(6,5)FBCPB
C
      FBVPB = FBVOL/BNCOM
C FBVPB =  AVE. VOL. PER BUNCH
      WRITE (6 ,6) FBVPB,NTREE,FBVOL,FBTNS,FBDIS
C
      CYCHR = FBACC/FBHR
      WRITE(6,7)CYCHR
C
      FBBMH = BNCOM/FBHR
C FBBMH = AVE. BUNCHES PER MACHINE HOUR
      FBTMH = NTREE/FBHR
C FBTMH = TREES FELLED PER MACHINE HOUR
      FBVMH = FBVOL/ FBHR
C FBVMH = VOL. FELLED PER MACHINE HOUR
      FBATH = FBTNS/FBHR
C  FBATH  AVERAGE TONS PER HOUR
      FBDMH = FBDIS/FBHR
C FBDMH = DIST. TRAV. PER MACHINE HOUR
      WRITE (6 ,8) FBBMH,FBTMH,FBVMH,FBATH,FBDMH
C
C  FELLER-BUNCHER GALLONS/HOUR
      FBGPT = FBGPH/FBATH
C  FELLER-BUNCHER GALLONS PER TON
      FBGPC = FBGPH/(FBVMH/100)
C  FELLER-BUNCHER GALLONS PER CUNIT
      FBTGU = FBGPH*FBHR
      WRITE(6,11)FBTGU,FBGPH,FBGPT,FBGPC
      RETURN
      END
```

APPENDIX C

COMPLETE FLOW CHARTS

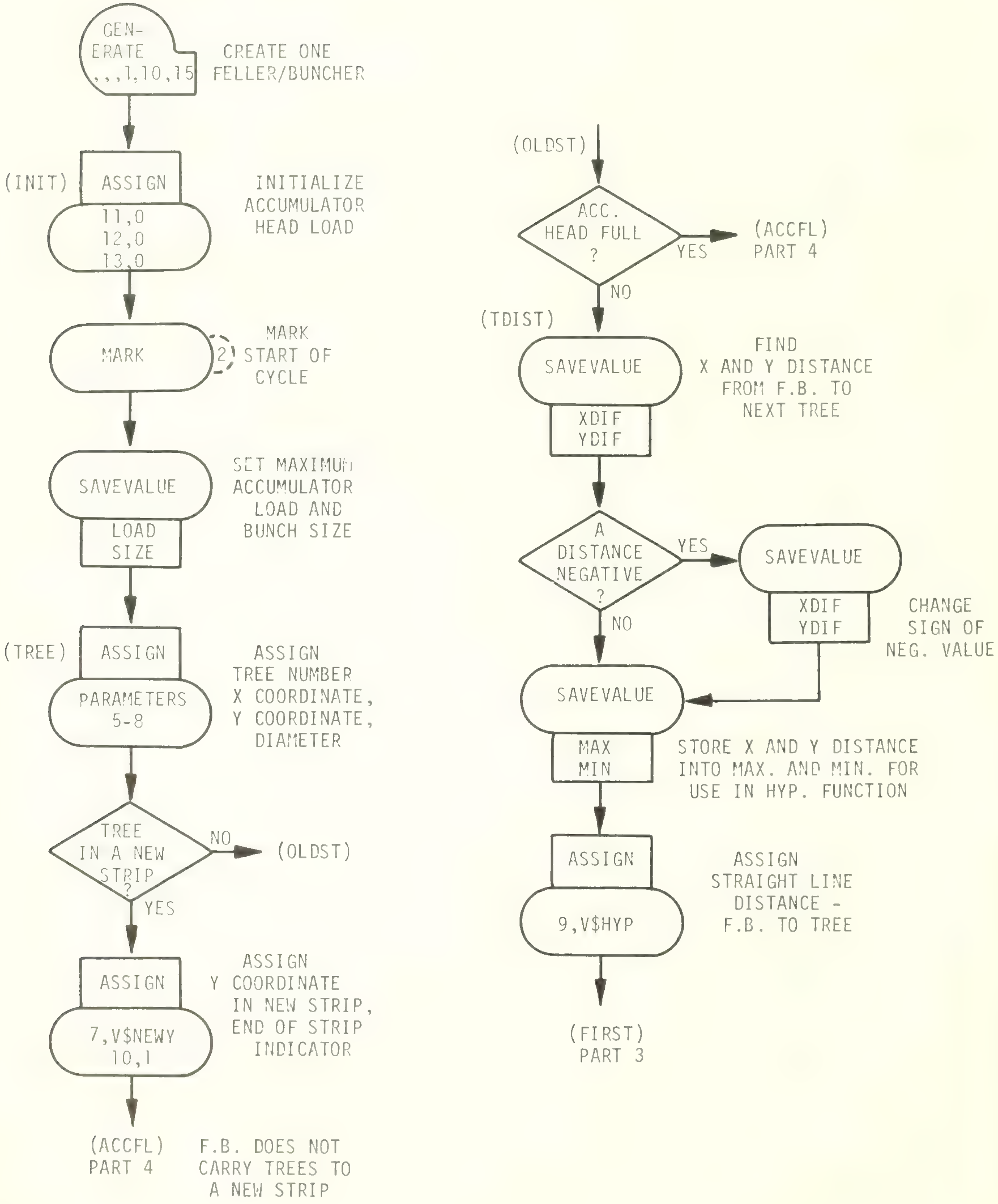
COMPLETE FLOW CHARTS - PART 1 OF 6

TIMER SEGMENT



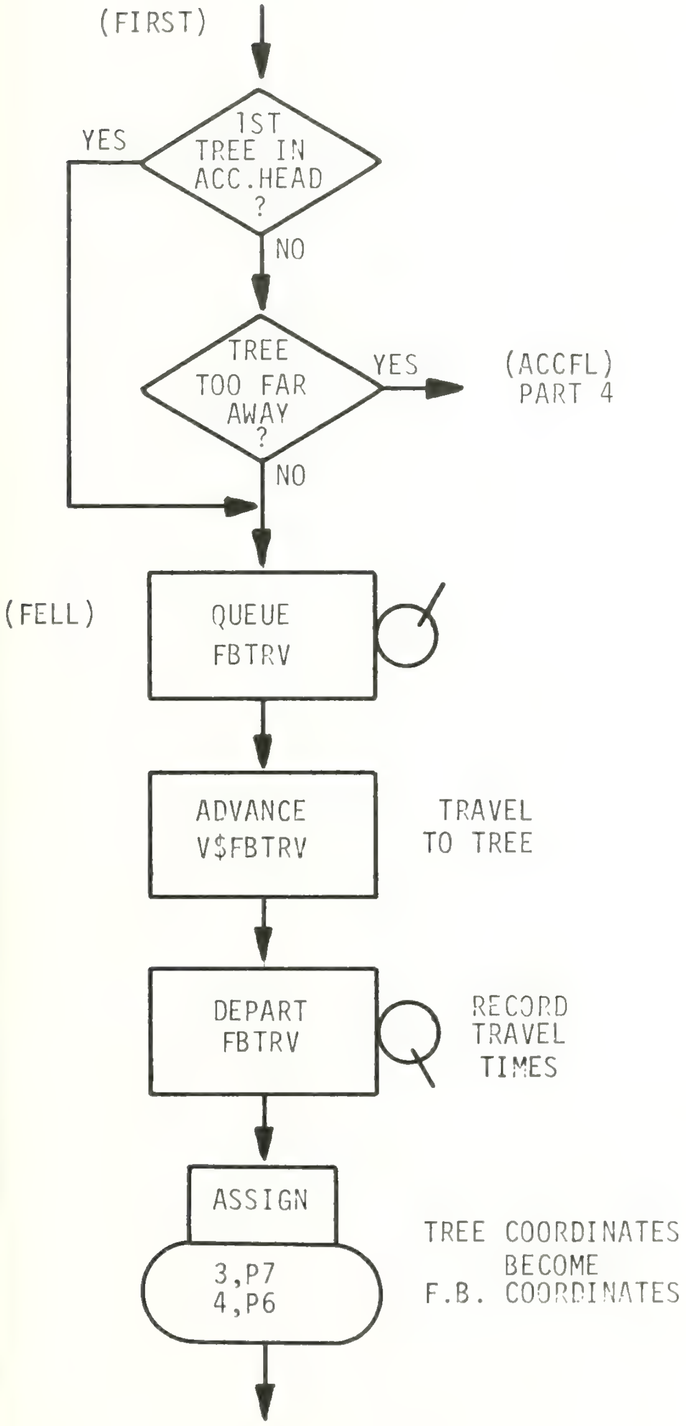
COMPLETE FLOW CHARTS - PART 2 OF 6

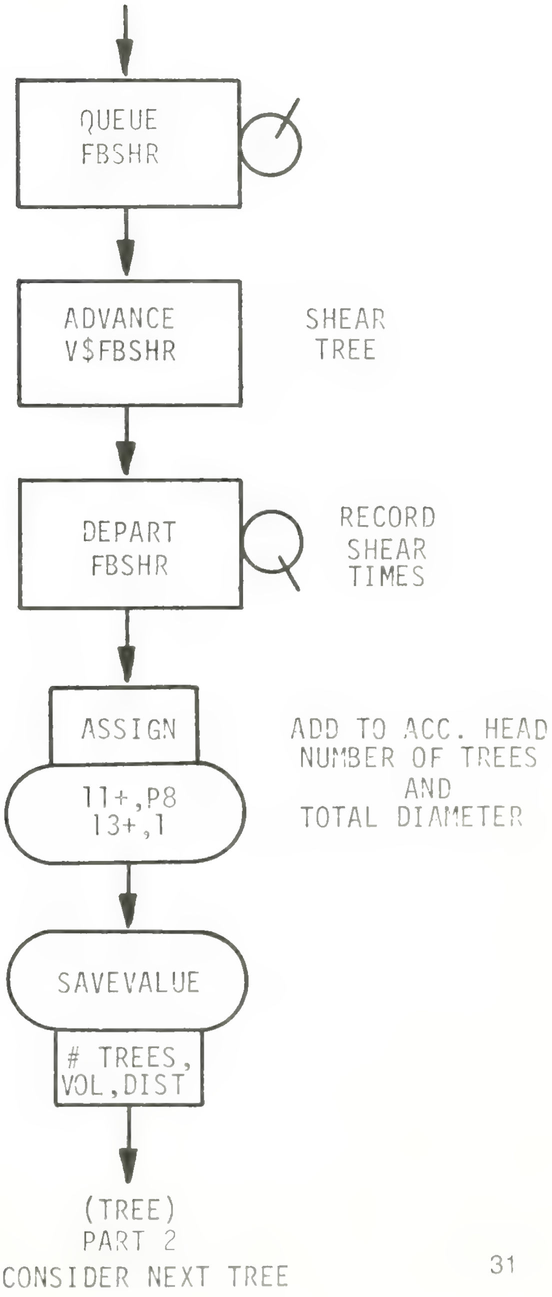
RUBBER TIRED FELLER/BUNCHER SEGMENT



COMPLETE FLOW CHARTS - PART 3 OF 6

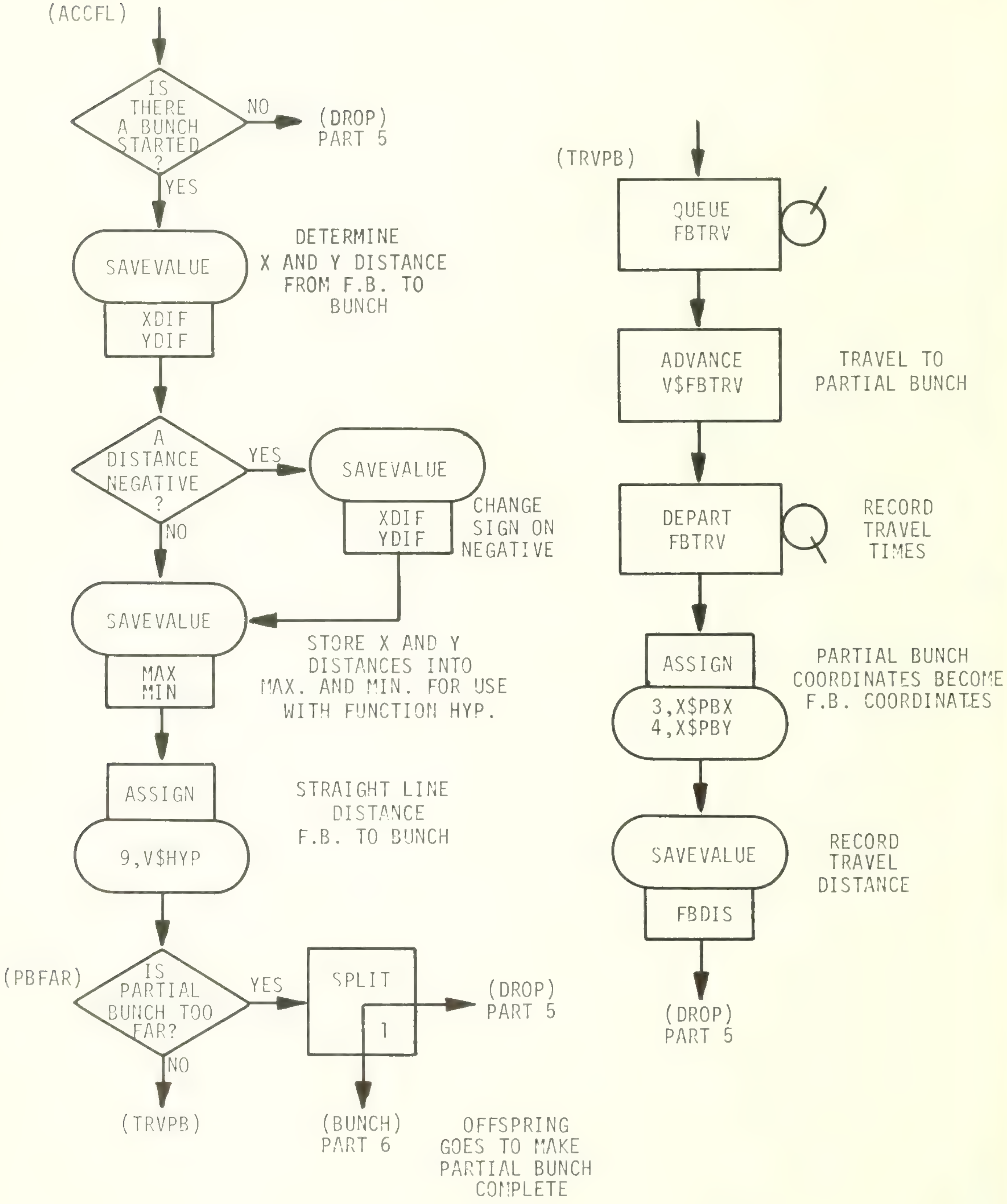
RUBBER TIRED FELLER/BUNCHER SEGMENT





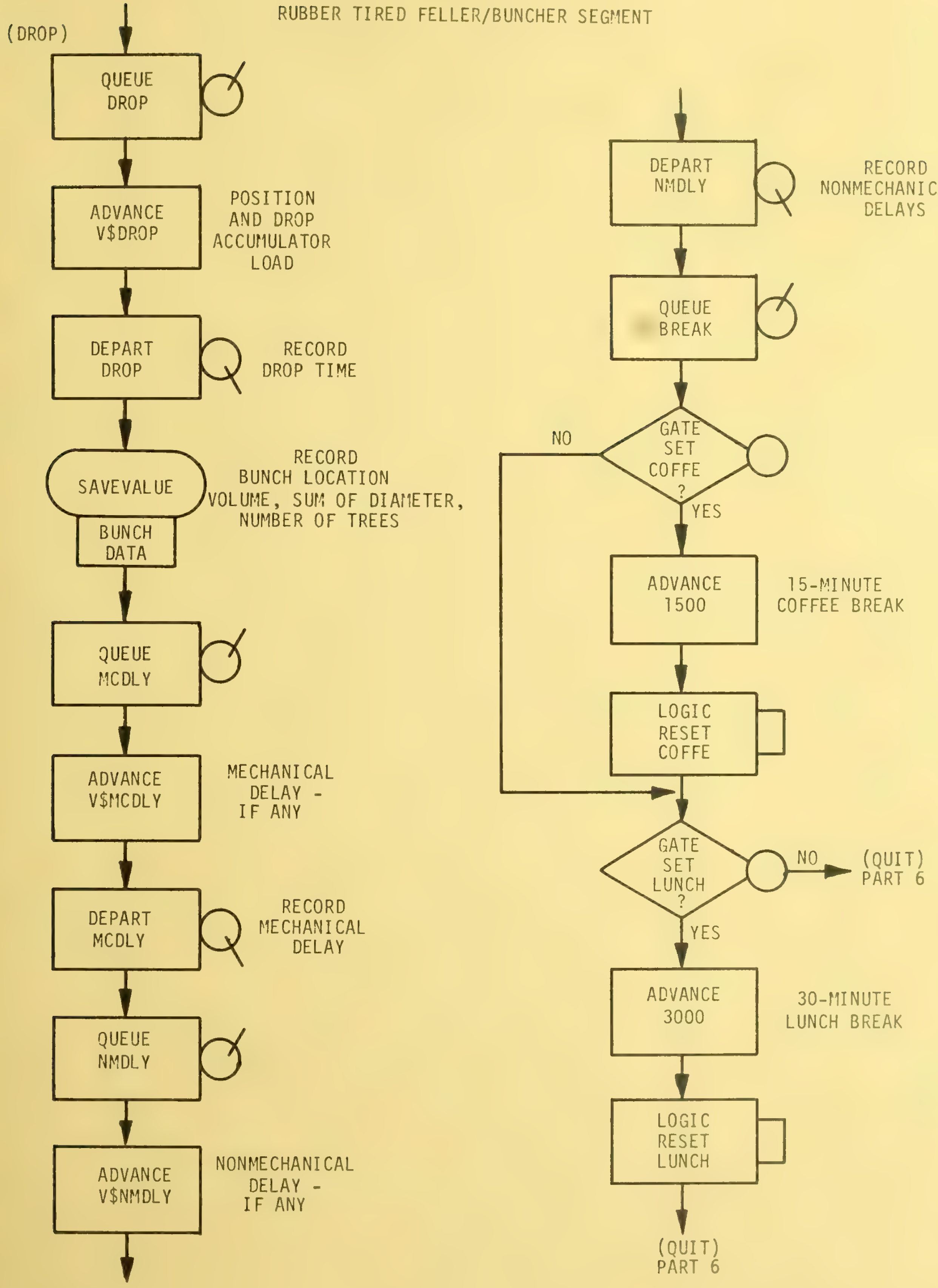
COMPLETE FLOW CHARTS - PART 4 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



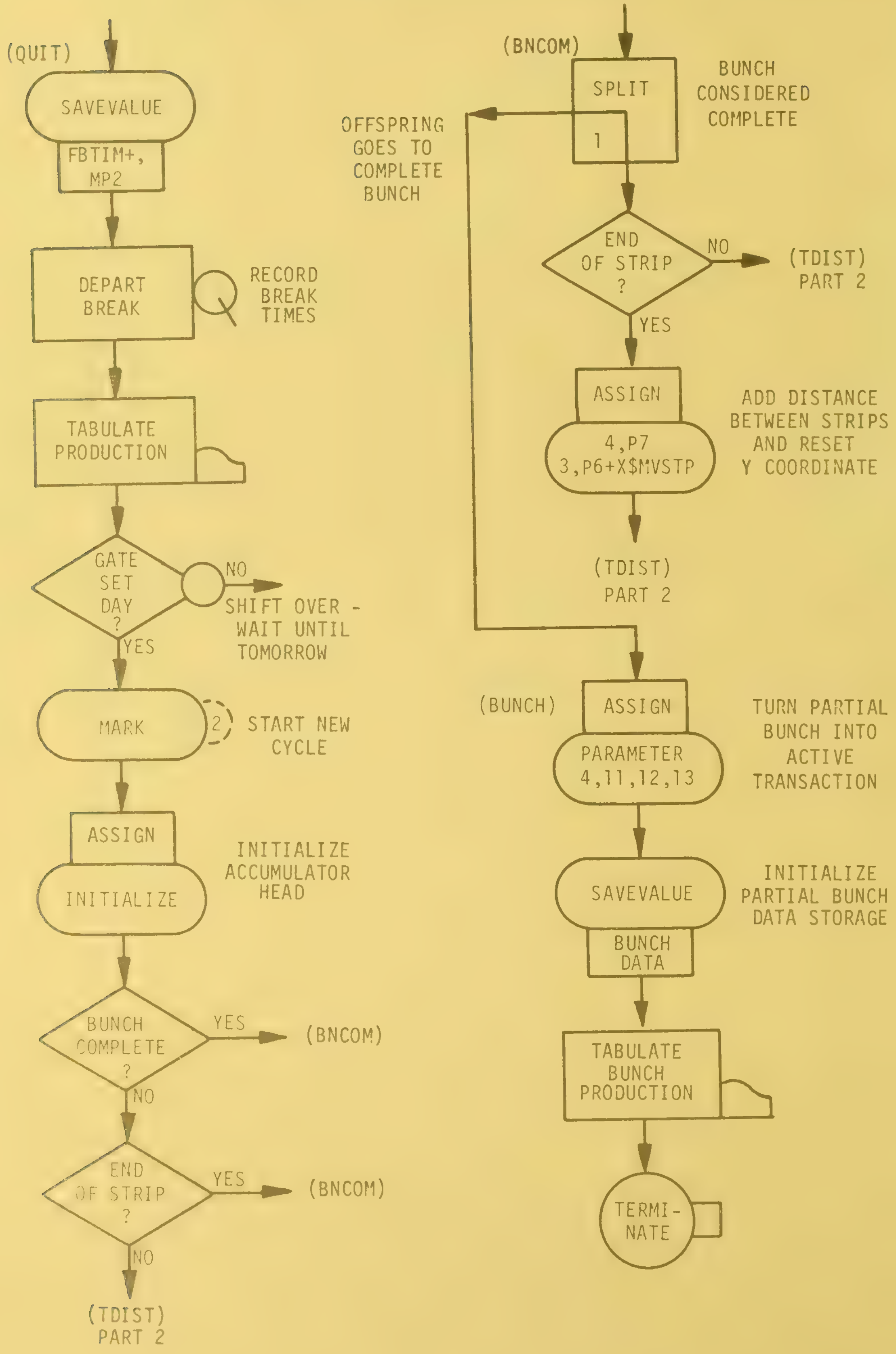
COMPLETE FLOW CHARTS - PART 5 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



COMPLETE FLOW CHARTS - PART 6 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



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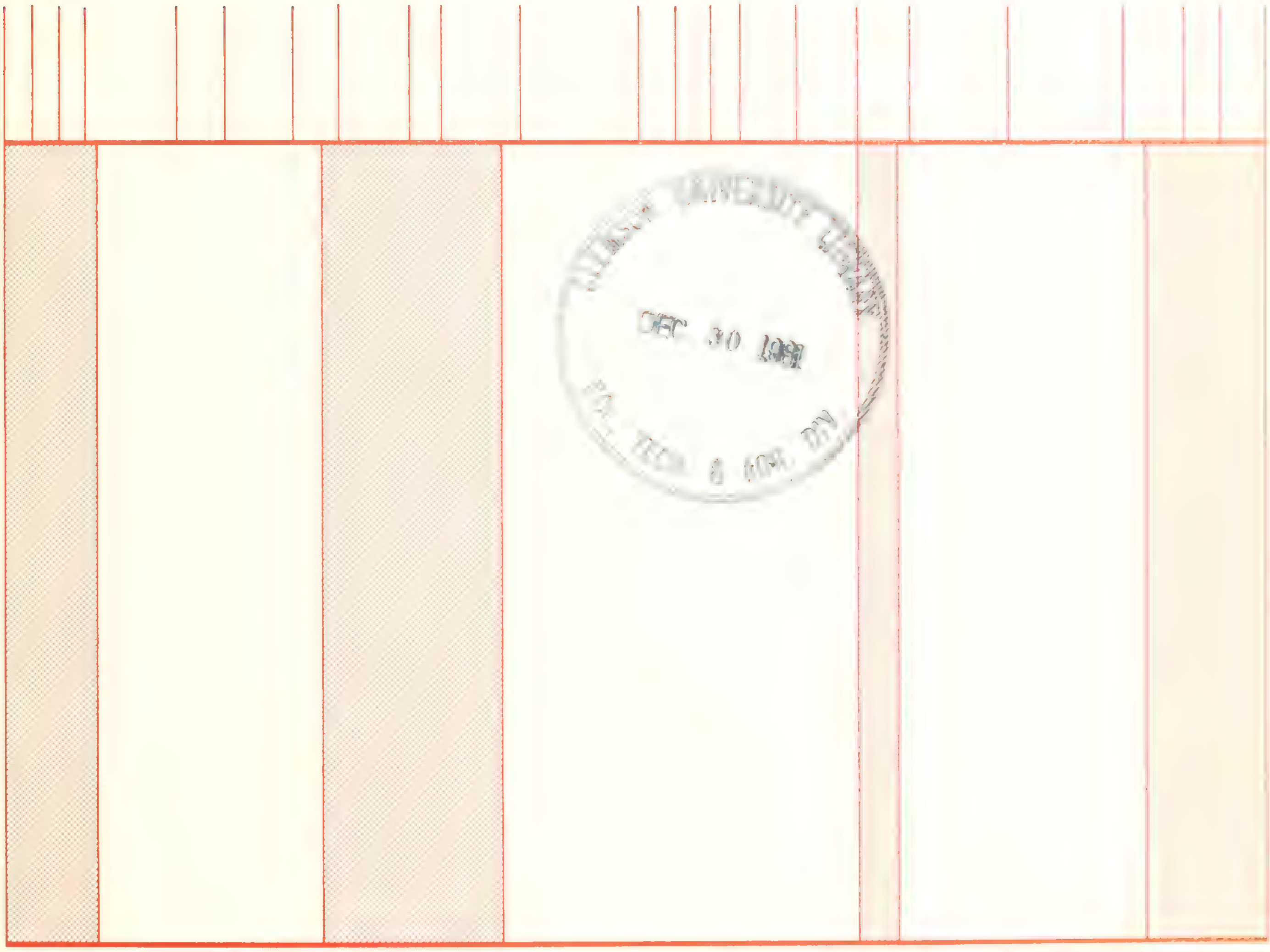
Research Paper
NC-213

Using Work Sampling to Analyze Logging Operations

Edwin S. Miyata, Helmuth M. Steinhilb, and Sharon A. Winsauer



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USING WORK SAMPLING TO ANALYZE LOGGING OPERATIONS

Edwin S. Miyata, *Research Industrial Engineer,*
Helmuth M. Steinhilb, *Research Forester,*
and **Sharon A. Winsauer,** *Computer Specialist,*
Houghton, Michigan

Managers of logging operations are faced with declining profits due to rapid increases in equipment costs, early obsolescence of equipment, and a gradual shift from harvesting large trees to smaller ones.

There are numerous ways to confront this problem of diminished returns. One of the simplest and least costly is to improve the efficiency of the logging operation. To do this, management must have accurate information regarding the interaction of men and machines and their performance in the woods. One way to obtain this needed information is to conduct work measurement studies.

There are three main ways to measure men and machines at work. The most common of these is the Gross Time Study method. This technique deals with gross production and total elapsed time. For example, if a piece of equipment produces 10 cords of wood in 8 hours (assuming the operator works 8 hours), the productivity of this equipment could be said to be 1.25 cords/hour. However, this information does not say how much time the equipment actually worked, how much time it was idle because of various delays, or what was the cause and extent of the delays. Thus, this method is not very useful for evaluating or improving the efficiency of a logging operation.

The second commonly used method of measuring work is the Continuous Time Study. This method utilizes a stopwatch in observing, measuring, and recording each well-defined phase of the operation for perhaps an entire day over many days or weeks. If the observer is properly qualified, this is probably the best method. However, it has the following disadvantages when applied to field operations such as logging:

- Requires highly skilled observers;
- Requires tedious recording of data over long hours for observers and operators;
- Becomes costly, because at least as many observers are required as there are pieces of equipment;
- Following and observing logging equipment continuously is hazardous and difficult;
- Reducing data is difficult and time consuming;
- Accuracy of data is questionable near the end of a long and exhausting day of collecting data.

The third method is Work Sampling. This is a statistically based method in which instantaneous observations are taken at random intervals. With proper design, each instantaneous observation is recorded, and the percentage of time for a particular activity is the number of observations for that activity divided by the total number of observations. This sampling method was originated by Tippett (1935) in 1927 under the name of "snap-reading" for measuring the productivity of various machines in the British textile industry. Morrow (1957) of New York University introduced this method to the United States under the name of "ratio-delay" in 1940, to study the ratio of delays to total scheduled time, and to find the causes of delays. Since its introduction in the U.S., work sampling has been applied in various industries (Brisley 1952, Herrick 1959, Mac Niece 1953, Rowe 1954) to effectively increase productivity and cut production costs.

The work sampling technique approximates the results obtained by the continuous time study and has the following advantages over the latter:

- It is cheaper as it does not require highly skilled observers; often a single analyst can observe mul-

tiple functions or separate machines concurrently;
- It is less tedious and tiresome for observers;
- It is safer than continuous time study in the field;
- Accuracy is controllable and can approach the precision of continuous measurements as the number of observations increase;
- Data reduction and analysis are much easier and shorter.

Despite these advantages, the application of work sampling technique to measure performance of logging operations has been limited. Lussier (1961) introduced the work sampling technique to analyze a single piece of logging equipment in 1965. Holemo and Dyson (1972) reported on the work sampling technique to analyze the downtime in sawmills. Both these well-written papers discuss the accuracy and the advantages of the work sampling method and explain its statistical basis. Nevertheless, the method has not received much attention and is not extensively used in the logging industry.

The purpose of this paper is to (1) present the results of the work sampling method and compare them with the results from the continuous time method, (2) determine the feasibility of using work sampling for the analysis of logging operations, and (3) define the limitations and capabilities of the work sampling method as applied to logging.

METHODS

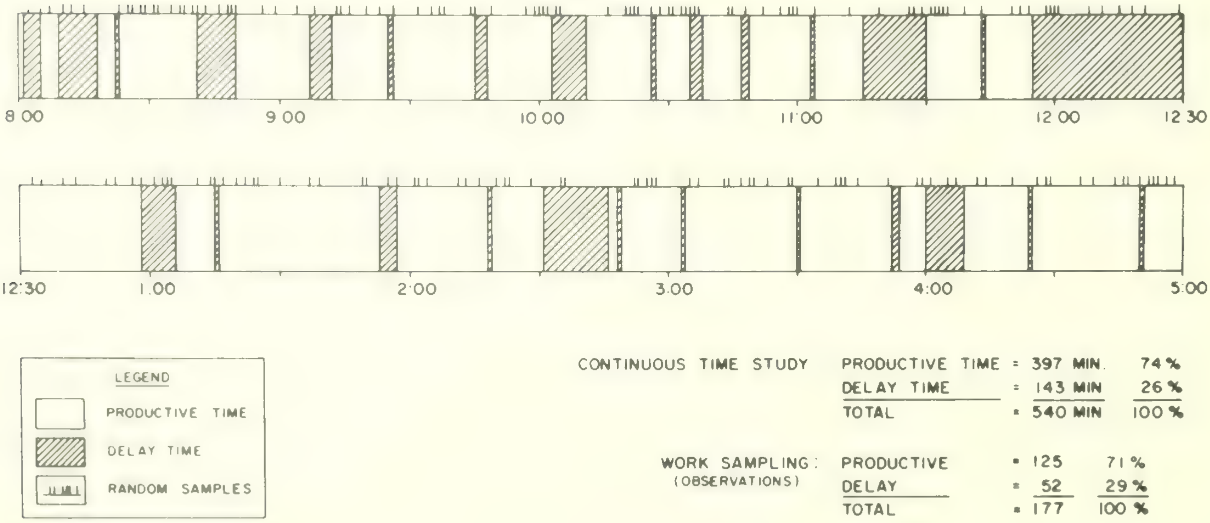
The study consisted of two parts. The first involved a simulated work sampling experiment, and the second, an actual field trial.

The objective of the simulated work sampling experiment was to determine the accuracy of the results of work sampling by comparing them with the results from a continuous time study.

The procedure of the simulated work sampling experiment was as follows:

1. Data from a continuous stopwatch study of a logging operation were selected. The pieces of equipment used were a feller/buncher, a skidder, and a chipper. A short description of their main operating characteristics are presented in the Appendix.
2. The data of the continuous stopwatch study was plotted on a time scale on graph paper as either productive or delay time (fig. 1).
3. From the graph, sample readings were taken at random times by using a table of random numbers.
4. The mathematical formula used to determine the number of work sample observations required was:

$$N = \frac{Z^2 Q}{E^2 D} \qquad (1)$$



CONTINUOUS TIME STUDY	PRODUCTIVE TIME	=	397 MIN.	74 %
	DELAY TIME	=	143 MIN	26 %
	TOTAL	=	540 MIN	100 %
WORK SAMPLING: (OBSERVATIONS)	PRODUCTIVE	=	125	71 %
	DELAY	=	52	29 %
	TOTAL	=	177	100 %

Figure 1.—*A simulated work sampling experiment (Barnes 1968). Data obtained from past continuous time study of a feller/buncher for 1-day operation.*

Where: N = Number of observations (sample size).

Z = A normal deviation which depends on the confidence level selected. If 90 percent confidence level is chosen, then the value of Z is 1.64. The values of Z for 99, 95, 85, and 80 percent confidence levels are 2.57, 1.96, 1.44, and 1.28, respectively.

D = Percentage occurrence of a delay, expressed as a decimal.

Q = (1-D) or the percentage occurrence of nondelay, expressed as a decimal.

E = Desired relative accuracy, expressed as a decimal.

5. The delay ratios for both the continuous time study and the work sampling method were calculated and compared to determine the accuracy of the work sampling technique.

The second part of the study was a field trial of work sampling on a logging operation different from the one on which the simulation study was made. The objective was to determine the feasibility, limitations, and field applications of work sampling on an actual logging operation. Two kinds of observations were made:

1. One piece of logging equipment was observed concurrently by both a work sampling observer and a continuous time study observer.
2. Three pieces of logging equipment were continuously observed by three continuous time study persons each obtaining data for one of the machines. At the same time, a work sampling person collected data on all three machines.

All the data were analyzed and the results presented below.

RESULTS OF THE SIMULATED WORK SAMPLING EXPERIMENT

In a controlled work environment and for standardized processes found in some fields of work, a 99 or 95 percent confidence limit with a 5 percent desired relative accuracy is often required. However, under the extreme variability of a logging operation, such high confidence limits and desired relative accuracies would demand an impractically large number of observations (table 1). We therefore decided to use a 90 percent confidence limit with a 10 percent desired relative accuracy to keep the number of observations at a practical level. In other words, the data obtained by work sampling has a 90 percent chance of representing the true facts, i.e., it will be in error 10 percent of the time, and the final result will be accurate within ± 10 percent.

To determine the number of observations by using equation (1), the percentage occurrence of the delay must be estimated. Delay ratios of 30, 35, and 35 percent as estimated from the past study were used for a feller/buncher, a skidder, and chipper, respectively. Sample sizes calculated for each piece of equipment are as follows:

For the feller/buncher: $Z = 1.64$ (90 percent confidence limit); $D = 0.30$ or 30 percent; $E = 0.10$ or 10 percent; $Q = 1 - 0.30 = 0.70$ or 70 percent, then the number of observations is:

$$N = \frac{Z^2Q}{E^2D} = \frac{(1.64)^2(0.70)}{(0.10)^2(0.30)} = 628 \text{ samples}$$

Similarly,

$$\text{Skidder: } N = \frac{(1.64)^2(0.65)}{(0.10)^2(0.35)} = 500 \text{ samples}$$

$$\text{Chipper: } N = \frac{(1.64)^2(0.65)}{(0.10)^2(0.35)} = 500 \text{ samples}$$

The continuous stopwatch study data for each piece of equipment were laid out on graph paper and presented as either working time or delay time along the continuous time scale. Sample observations were made at random times determined by the use of a random number table. As an illustration, figure 1 illustrates a simulated work sampling experiment for a 1-day operation of the feller/buncher. Each sample (tick mark) was noted and recorded as "delay" or "productive."

Delay ratios were calculated for the continuous time study as:

$$\text{Delay ratio} = \frac{\text{Total delay time}}{\text{Total time}}$$

and for the work sampling as:

$$\text{Delay ratio} = \frac{\text{Number of observations of delay}}{\text{Total number of observations}}$$

The available data were sampled for each piece of equipment (feller/buncher, skidder, and chipper). When the results from the continuous time study and the work sampling method were compared, the delay ratios (expressed in percent) were very similar (table 2).

Table 1.—*Number of observations for various confidence limits with different desired relative accuracy (as an example, a feller/buncher was used, D = 0.30 or 30 percent)*

Confidence limits (percent)	Desired relative accuracy 5 percent	10 percent
99	6,165	1,542
95	3,586	897
90	2,511	628

To illustrate the accuracy of the work sampling method, a 95 percent confidence interval of the delay ratios was calculated for the sample data. The formula used to determine the confidence interval is:

$$\hat{P} - Z\sqrt{\frac{\hat{P}(1-\hat{P})}{N}} < P < \hat{P} + Z\sqrt{\frac{\hat{P}(1-\hat{P})}{N}} \qquad (2)$$

Where: $\hat{P}$ = The ratio of delay in the sample.

P = The true proportion of delay. In this experiment, the value of P (continuous time study) is assumed to be "true" value.

Z = The normal deviation; depends on the confidence level chosen.

N = Sample size.

For the feller/buncher, the proportion of delay in the sample was found to be 0.32 or 32 percent, Z = 1.96 for 95 percent confidence limits, and N = 703.

$$0.32 \quad 1.96\sqrt{\frac{.32(1-.32)}{703}} < P < .32 + 1.96\sqrt{\frac{.32(1-.32)}{703}}$$

which simplifies to

$$0.29 < P < .35.$$

Therefore, from the work sample the true proportion of delay (delay ratio) can be inferred to be between 29 and 35 percent at a 95 percent confidence level.

Similarly, 95 percent confidence intervals were constructed from the work sampling data for the skidder and chipper (table 3).

RESULTS OF THE FIELD TRIAL

In addition to obtaining delay ratios and machine utilization figures, we wanted to find out if the work sampling technique could be used to determine the cause and kind of delay.

Field trials were carried out in cooperation with a local logger for 4 pieces of equipment (see Appendix for operating characteristics). A feller/buncher was observed by both a work sample observer and a continuous time study observer. The other three pieces of equipment— a chipper, a dozer, and a chain flail— were concurrently monitored by a single work sampling observer and three continuous time study observers. All observers recorded working and delay time and the causes of the delays. The results of the continuous time study and the work sampling for each piece of equipment are presented in table 4.

To test the accuracy of the work sampling technique, a 95 percent confidence interval (or Z = 1.96 in equation 2) was calculated for the sample data. These confidence intervals are compared with the delay ratios obtained from the continuous time study in table 5.

The comparison in table 5 shows no significant difference in the delay ratios obtained from work sampling and continuous time study with the exception of the chain flail. The lack of agreement in the chain flail data may be caused by the inexperience of the continuous time study observer, or it may be due to chance.

Table 2.— *Delay ratio obtained from the two different techniques*

	Continuous time study			Work sampling		
Equipment	**Total time**	**Delay**		**Total samples**	**Delay**	
	Minutes	*Minutes*	*Percent*	*Count*	*Count*	*Percent*
Feller/ buncher	1,888	566	30	703	228	32
Skidder	1,474	611	41	481	202	42
Chipper	1,478	754	51	510	268	53

Table 3.— *A summary of 95 percent confidence intervals on delay ratio for feller/buncher, skidder, and chipper*
(In percent)

Equipment	95 percent confidence interval on delay ratio	True delay ratio (P)[1] (from continuous time study)
Feller/ buncher	29 < P < 35	30
Skidder	38 < P < 46	41
Chipper	49 < P < 57	51

[1] In this experiment, the value of P (continuous time study) is assumed to be "true" value.

Table 4.—*Comparison of continuous time study and work sampling obtained from the actual logging operation*

Equipment	Continuous time study				Work sampling			
	Total time	Delay	Delay ratio	Machine utilization[1]	Total observation	Delays	Delay ratio	Machine utilization[1]
	Minutes	*Minutes*	*Percent*	*Percent*	*Number*	*Number*	*Percent*	*Percent*
Feller/buncher[2]	1,277	365	29	71	529	154	29	71
Chipper[3]	2,073	905	44	56	894	380	43	57
Dozer[3]	2,130	424	20	80	895	195	22	78
Chain flail[3]	2,134	1,104	52	48	893	415	46	54

[1] Machine utilization equals 100 percent minus delay ratio or productive time divided by total time (scheduled hours) times 100

[2] Equipment observed by both a work sampling observer and a continuous time study observer.

[3] Each piece of equipment observed by a continuous time study observer, but all three observed simultaneously by one work sampling monitor

Table 5.—*Ninety-five percent confidence interval test*
(In percent)

Equipment	95 percent confidence intervals	Value of P (continuous time study)
Feller/buncher	$25 < P < 33$	29
Chipper	$40 < P < 46$	44
Dozer	$19 < P < 25$	20
Chain flail	$43 < P < 49$	52

The random work sampling technique gives excellent results for delay ratio or total delay time, and thus gives good results for machine utilization (table 6). Logging operations conducted by independent loggers often have no fixed schedule of work hours as manufacturing operations do. The working hours vary from job to job, day to day, and often, season to season, and may depend upon the piece of equipment. Therefore, machine utilization was defined as total productive time divided by the total scheduled hours during the study period.

Delays due to lunch, when they occurred, are also included in total delay time. This procedure was chosen since there was no fixed lunch period, and some equipment operators took a lunch break at the same time, some at different times, while others did not take a lunch break but ate during productive time.

Table 6.—*Comparison of continuous time study and work sampling for machine utilization, delay ratio, and delay categories*

	Feller/buncher		Chipper		Dozer	
	Continuous time study	Work sampling	Continuous time study	Work sampling	Continuous time study	Work sampling
	Percent					
Machine utilization (percent)	71	71	56	57	80	78
Delay ratio (percent)	29	29	44	43	20	22
Delay categories	*Percent of total delay*					
Personal[1]	61.5	55.2	1.6	3.7	22.2	25.1
Operational	28.4	35.1	15.0	16.2	1.1	1.0
Mechanical	10.1	9.7	6.3	6.8	0.0	0.0
Not in use	0.0	0.0	0.0	0.0	76.7	73.9
Change vans	0.0	0.0	77.1	73.3	0.0	0.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

[1] Includes lunch break where it can be isolated.

Total delay for the feller/buncher, chipper, and dozer was broken down into broad categories (table 6). Work sampling gives reasonably accurate results for the breakdown of total delay into delay categories.

There is a limit to the size of the work element or delay element that can be accurately determined by work sampling. For small or infrequently occurring elements, the work sampling technique is not as accurate as continuous time study unless an impractically large number of samples are taken (table 7).

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn from this study:

1. Random work sampling, when used properly, can obtain performance and productivity data on logging operations at less cost and with fewer hazards than continuous timing. The degree of accuracy is also sufficient for planning and improving logging operations.
2. When the total delay time is broken down into five broad categories (table 6) work sampling gives reasonably accurate results for each of the individual categories.
3. For work elements that are small or occur infrequently, work sampling will not give as good results as continuous timing, unless very many observations are taken (table 7).
4. Work sampling appears to be an adequate method for studying performance and productivity in logging, since it discovers and measures the larger work elements with sufficient accuracy to plan for maximum productivity.
5. Extensive and thorough training of observers is not as crucial in work sampling as it is in continuous time studies. However, the observer must know logging machines and operations well enough to determine what the equipment is doing at any instant of observation.
6. Random work sampling has a disadvantage. In operations where the logging equipment is widely scattered or where visibility is poor, the random observations may occur at such short intervals that the observer cannot adequately observe all the equipment. However, when visibility is good, the observer could obtain the data on several machines at the same time thus reducing study costs as compared to continuous time studies where a separate observer would be needed for each machine.

Table 7.—*Classification of delay causes.*

(In percent)

	Feller/buncher		Chipper		Dozer	
Delay causes	Continuous time study	Work sampling	Continuous time study	Work sampling	Continuous time study	Work sampling
Personal:						
Lunch	32.8	31.8	—	—	9.6	6.6
Break and others	28.7	23.4	1.6	3.7	12.6	18.5
Operational:						
Wait for equipment or wood	—	—	13.9	12.0	0.8	1.0
Help other equipment	1.5	2.6	—	—	0.3	0.0
Clearing	18.4	22.7	1.0	4.2	—	—
Manipulate logs	3.0	3.9	—	—	—	—
Other	5.5	5.9	0.1	0.0	—	—
Mechanical:						
Refuel	—	—	0.3	0.8	—	—
Maintenance	—	—	6.0	6.0	—	—
Repair	10.1	9.7	—	—	—	—
Not in use	—	—	—	—	76.7	73.9
Change vans:						
Change vans only	—	—	26.9	27.5	—	—
Vans and lunch	—	—	25.7	20.7	—	—
Vans and maintenance	—	—	13.7	13.1	—	—
Vans and move chipper	—	—	10.8	12.0	—	—
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

7. Work sampling could be carried out as an ongoing project of going logging operations to maintain the standardized production rate, to detect any departures from this rate, and the reasons for such departures.

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APPENDIX

Short Description and Definition of Activities of Logging Equipment Used in the Work Sampling Study

Feller/buncher (Drott 40LC): A self-propelled track-type machine with an articulated boom which has holding clamps, accumulator, and shear head attached at its lower end. It is designed to shear a tree at the stump, hold it by means of a clamp, then swing and place the tree with others in a bunch.

Productive activities.— Travel, swing, and position boom to tree; position shear and holding clamp; shear tree; transport and boom in; swing and drop on bunch.

Delay.— Any activities besides above.

Grapple skidder (John Deere 740): A wheeled skidder with frame steering and four-wheel drive, equipped with a hydraulically actuated grapple and a small, hydraulically controlled, front-mounted dozer blade for decking and miscellaneous applications.

Productive activities.— Travel to bunch, position, grapple, open grapple and grasp bunch, lift and set, transport to predetermined area (usually landing), and position and drop the load alongside other tree bundles.

Delay.—Any activities besides above.

Chipper (Morbark 22″ XL): A mobile machine with an articulated boom and grapple, which reduces logs and whole trees to small chips by means of a rapidly rotating disc containing chipping knives. Chips are directly blown to transport unit.

Productive activities.— Swing and boom out to trees, position grapple, grasp, lift and swing, feed to conveyor, chipping.

Delay.— Any activities besides above.

Chain flail: A mobile machine designed to remove bark, leaves, and branches from trees by the use of a rapidly rotating shaft with chains attached which strike and beat the crown of the tree.

Productive activities.— Travel to the bunch (or deck), positioning, lowering the chain flail attachment, chain-flailing the trees in the bunch, moving over the bunch until most of the smaller branches are removed.

Delay.— Any activities besides above.

Miyata, Edwin S., Helmuth M. Steinhilb, and Sharon A. Winsauer.

1981. Using work sampling to analyze logging operations. U.S. Department of Agriculture Forest Service, Research Paper NC-213, 8 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Discusses the advantages and disadvantages of various time study methods for determining efficiency and productivity in logging. The work sampling method is compared with the continuous time-study method. Gives the feasibility, capability, and limitation of the work sampling method.

KEY WORDS: Work sampling, productivity, delay ratio, time study methods, work measurement.

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Unstaffed Trail Registration Compliance

in a Backcountry Recreation Area

Earl C. Leatherberry and David W. Lime

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North Central Forest Experiment Station
U.S. Department of Agriculture—Forest Service
1992 Folwell Avenue
St. Paul, MN 55108

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UNSTAFFED TRAIL REGISTRATION COMPLIANCE IN A BACKCOUNTRY RECREATION AREA

Earl C. Leatherberry,
Geographer,
and **David W. Lime,**
Research Social Scientist

Nationwide, people are increasingly using trails to enjoy the out-of-doors. According to the Heritage Conservation and Recreation Service (formerly the USDI Bureau of Outdoor Recreation 1967; 1973), the number of people taking nature walks increased from 20 to 34 million between 1965 and 1972, while backpackers increased from an estimated 10 to 12 million. Participation in other trail activities such as horseback riding and off-road vehicle use also has greatly increased (Lucas and Rinehart 1976).

Many trails are on public and private land best described as "backcountry" and ranging from designated Wilderness Areas to agricultural or even urban fringe environments that convey a "wild" feeling. Most backcountry recreation areas provide opportunity for dispersed, away-from-the-road activities.

Resource managers need information on how and by whom trails are used and also on use trends to determine the necessity of trail facilities, the kinds and locations of desired facilities, and the maintenance and law enforcement schedules needed. Managers often rely on unstaffed, self-issuing trail registers to secure such information. The trail user is asked to complete either a "mandatory" or "voluntary" registration form. Until fairly recently, voluntary guestbooks were often used. Now, a registration card system is used more often.

Unstaffed trail registers have been used for many years by the U.S. Forest Service, particularly in Wildernesses and Primitive Areas, and on National Park Service trails. Information collected often includes group size, travel route or destination, length of stay, method of travel, activities participated in, and the group leader's name and address. Registers normally are located at or near trailheads—not at a central registration point such as a ranger station or visitor center. They are relatively inexpensive to install and maintain, and their operation requires no staffing increase.

The problem with such a system is that not all people register. While voluntary trail registration compliance on backcountry trails can be high—an 89 percent compliance rate was recorded in Colorado's Rawah Wilderness (James and Schreuder 1972)—it can be low too. Only 28 percent of the groups entering the Selway-Bitteroot Wilderness in Montana (Lucas, 1975) complied with voluntary registration requests.

Are unstaffed trail registers really effective in securing information from trail users? Are some types of visitors more likely to register than others? Are some trail register designs and locations more effective than others?

To answer these questions, we present findings from a study that monitored compliance continuously at an unstaffed trail register in an upper midwestern backcountry area. The study was designed to evaluate the effectiveness of unstaffed trail registers in securing information from backcountry recreationists. Two kinds of self-issued registration forms—mandatory and voluntary—were evaluated. Also, to determine factors influencing registration compliance or noncompliance certain characteristics of visitor groups and their use patterns were delineated to determine their possible relation to compliance. The characteristics were: group size, dominant recreation activity pursued, season of visit, time of day the visitor entered the area, and length of stay. A study using similar methods has been completed by the Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Missoula, Montana (Lucas and Kovalicky 1981).

STUDY AREA

Compliance with registration requirements at an unstaffed trail register was tested on the Cyrus H. McCormick Experimental Forest in the upper Peninsula of Michigan (fig. 1). The Forest is about 40 miles

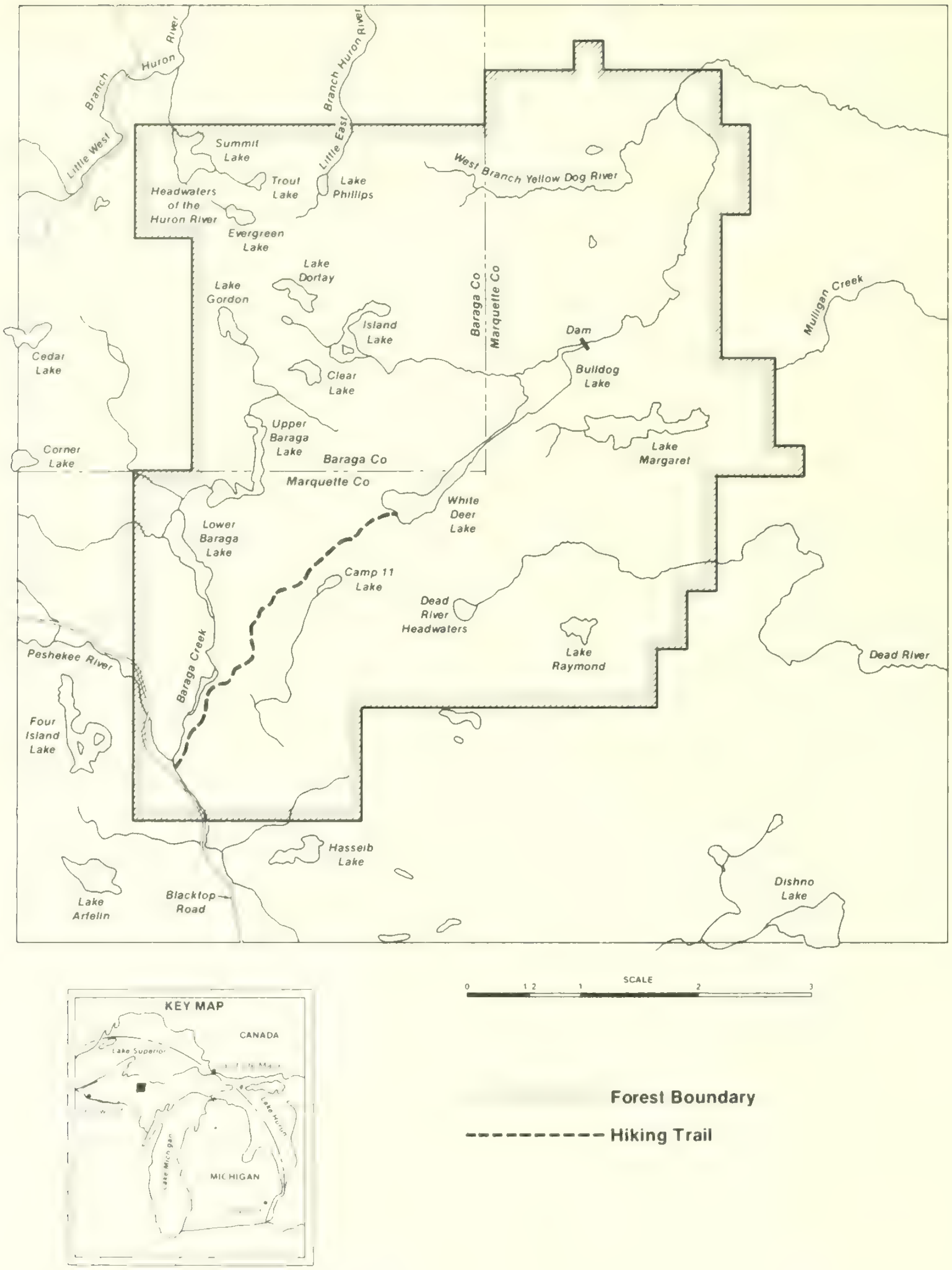


Figure 1.—*Cyrus H. McCormick Experimental Forest, Ottawa National Forest.*

west of Marquette and was deeded to the U.S. Forest Service in 1969 for research purposes. The Forest is administered by the Ottawa National Forest and the North Central Forest Experiment Station.

The Forest is a 17,124 acre roadless area with several large lakes and numerous small lakes and streams (fig. 2). The topography is rolling to rugged with rock outcrops common; vegetation types are varied. The area is designated for day-use recreation only, and hiking is the predominant recreational pursuit. There are about 125 miles of hiking trails on the Forest, but many are not maintained and are in poor condition.

The unstaffed trail register was located on the most heavily used trail in the southwest quadrant of the Forest (fig. 1). The 3-mile trail, leading from a paved county road, follows the old road to the former McCormick estate (fig. 3). At least 90 percent of the visitors enter and exit here.

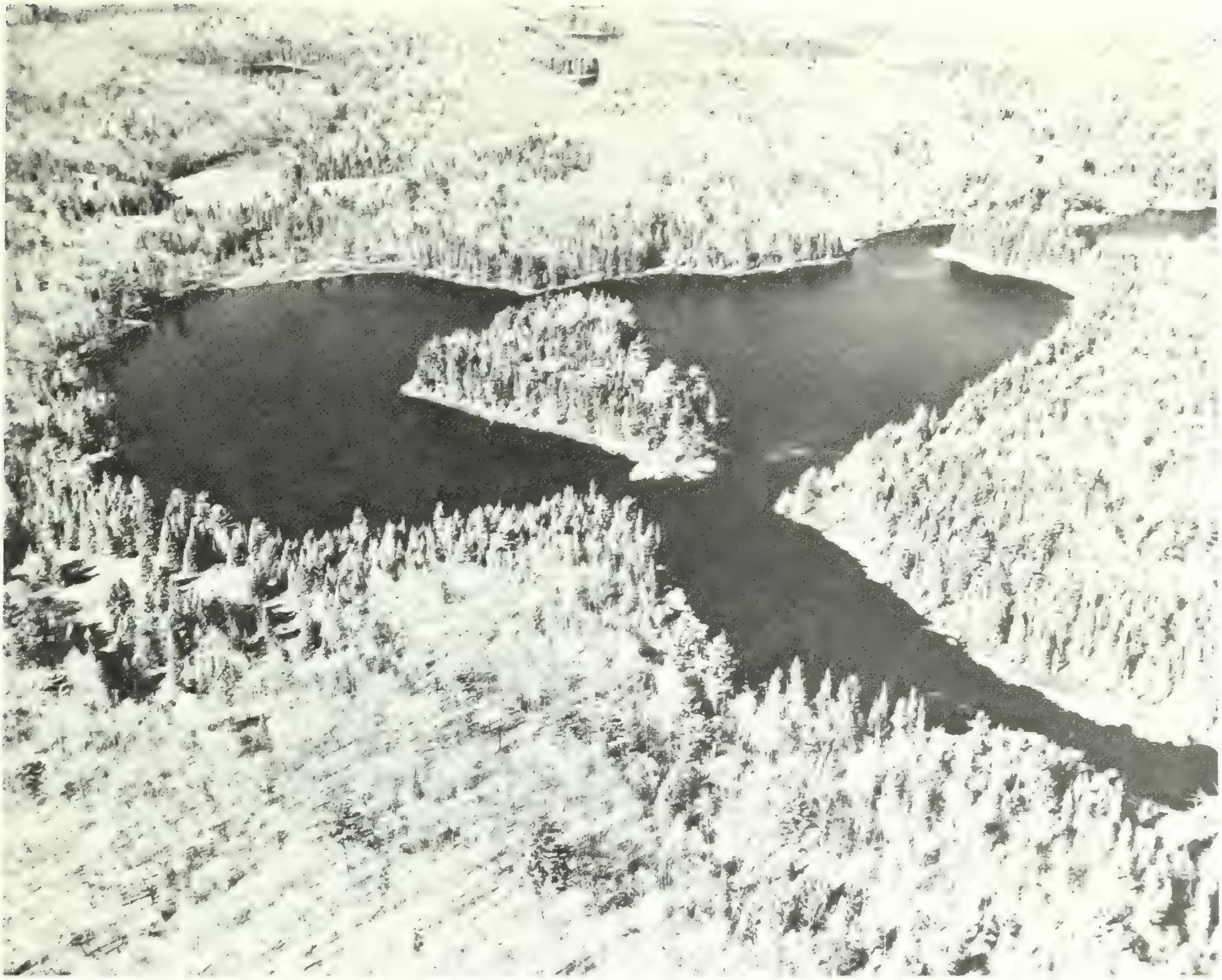


Figure 2.—*Island Lake and surrounding terrain is typical of the environment in the McCormick Experimental Forest.*

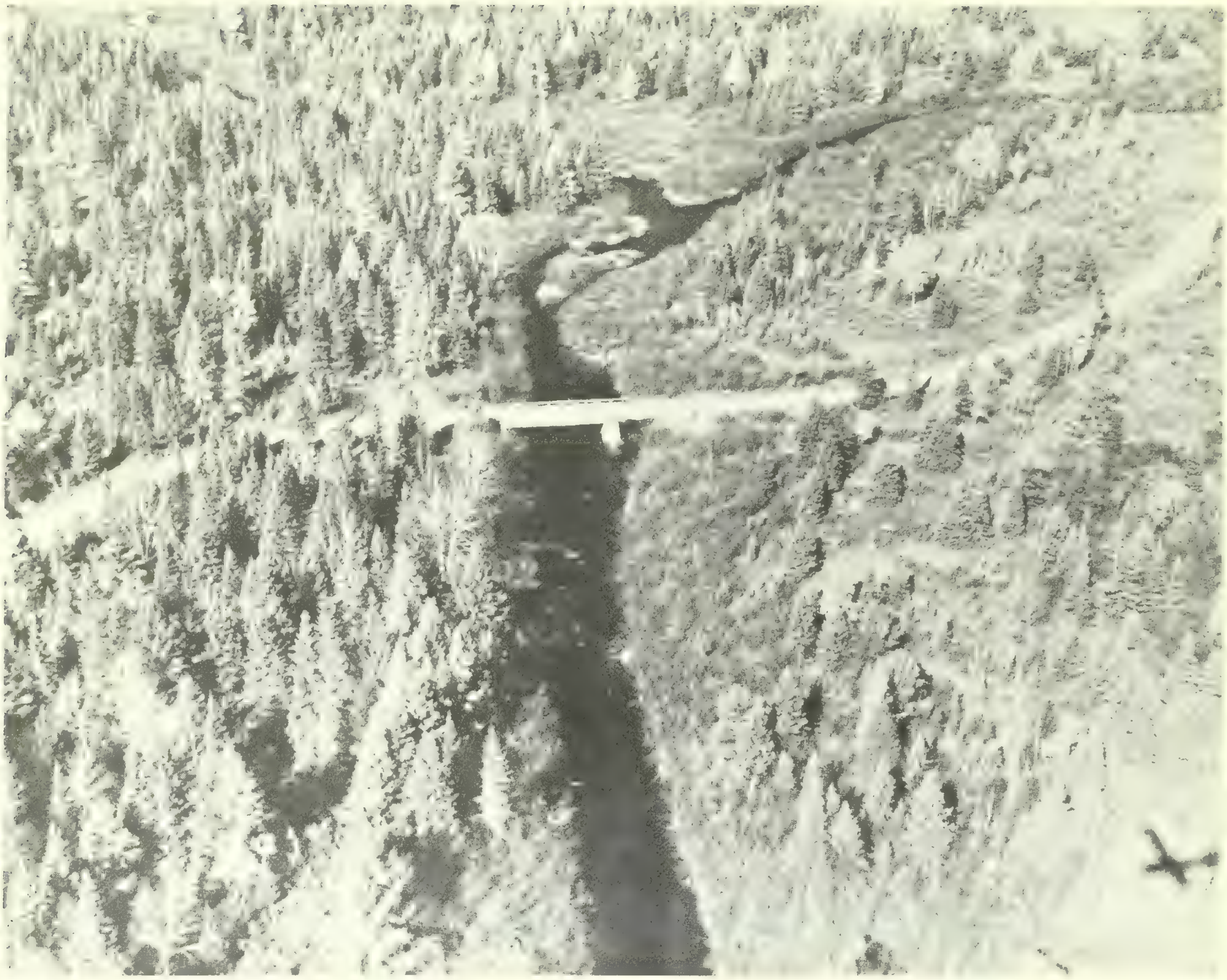


Figure 3.—*A 3-mile unpaved road is the main hiking trail on the Forest. Most visitors enter and exit the Forest using this road.*

STUDY PROCEDURES

Registration compliance was monitored from August 4 to September 30, 1978, and from May 22 to October 15, 1979. During the 1978 period, 83 groups entered the area while in the 1979 period, 241 groups entered.

The trail register was a bulletin board, located approximately 400 feet up the trail and out of sight of the parking area (fig. 4). Affixed to the board was a box; the top half contained registration materials (forms, pencils, and calendar) and the bottom half served as a depository for completed forms (fig. 5). Also attached to the board was a plastic laminated map of the Forest, rules and regulations, and signs stating registration instructions.

Two registration forms were evaluated: (1) a self-issued "mandatory" form and (2) a self-issued "voluntary" form (fig. 6). As implied, the completion of the self-issued mandatory form was required. The instructional sign focused on the obligatory nature of the requirement and read, "One Person From Each Group **Must Register** Here." A group-designated leader was to complete the permit-like form, deposit one copy of the form at the register, and carry the other while in the area. This form, called the Self-issuing McCormick Permit, should not be confused with the mandatory permit often required in designated Forest Service Wildernesses. In this study the visitor did not know there was a copy of the form to be carried and possibly shown to a Forest Service officer until the form was removed from the registration

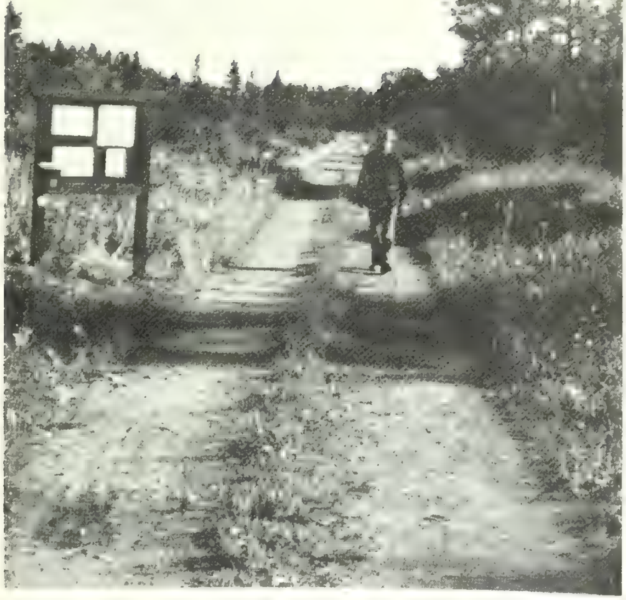


Figure 4.—*The unstaffed trail register was placed along the trail a short distance from the parking area and plainly visible to trail users.*

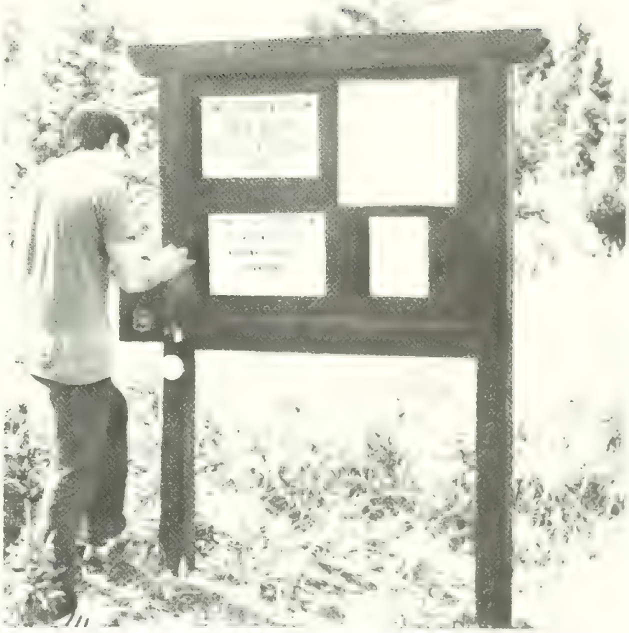


Figure 5.—*On the bulletin board were registration materials and a box for completed forms, a map of the Forest, rules and regulations, and signs pertaining to registration.*

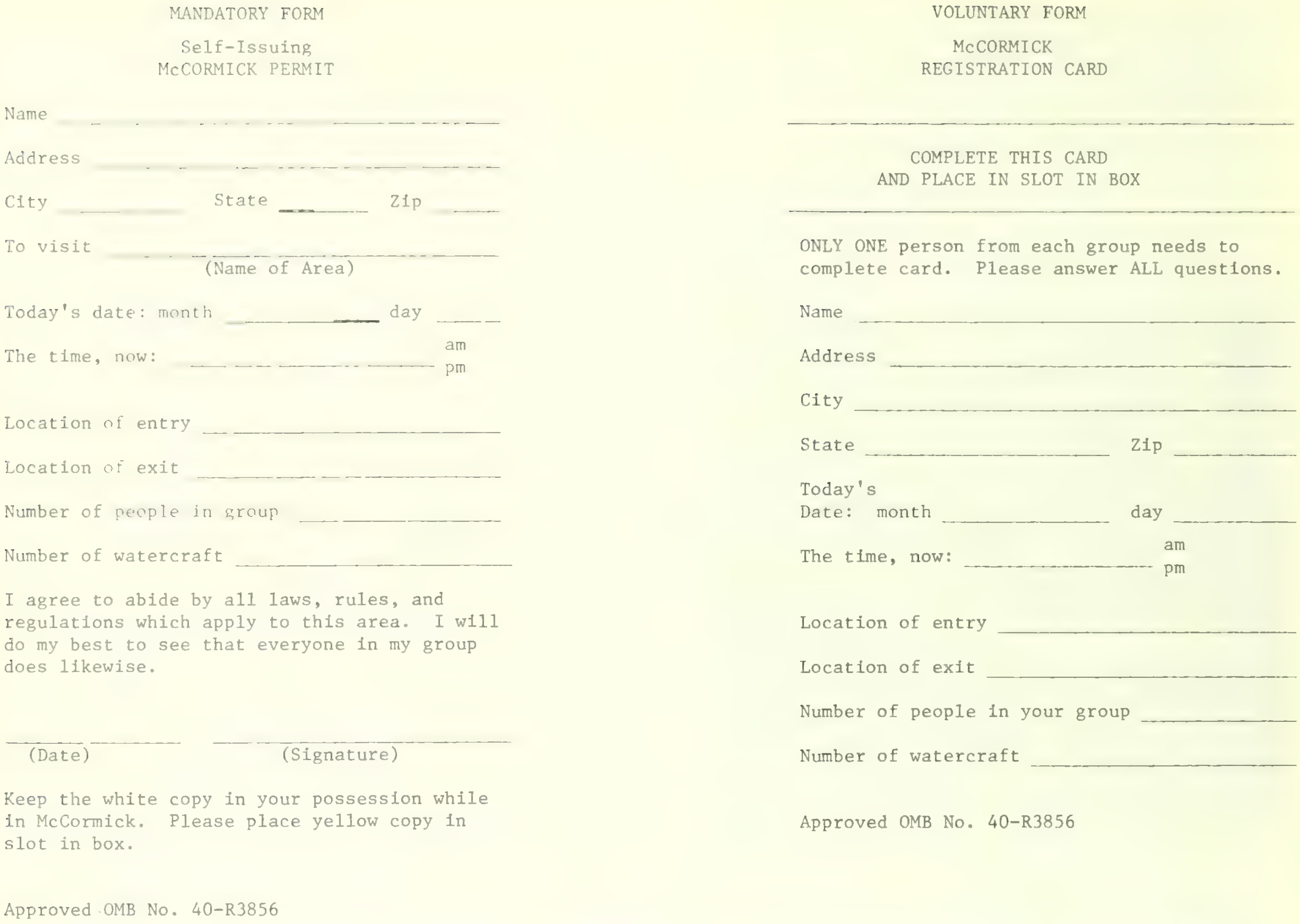
box. As such, some visitors may have viewed the system as a simple trail register with an authoritarian message.

The self-issued voluntary registration used the nonauthoritarian approach, and the sign was more solicitous: "One Person From Each Group **Please Register** Here." After completion, the entire voluntary form was to be deposited at the register.

Registration signs, forms, and instructions were rotated each Wednesday. At all times, as an incentive for registering, a free map of the Ottawa National Forest, was offered. A sign (fig. 5) advising people of the map was on the bulletin board: "For Your Cooperation A Free Map of the National Forest is Available—Please Take Only One Map per Group." Maps were stored in the top half of the registration box.

To monitor compliance and the effects of the two registration signs, an electric-eye trail traffic-counter and a super-8 movie camera system developed by the Forest Service's Equipment Development Center in Missoula, Montana (Gasvoda 1978) were used. The camera and counter were located out of sight and camouflaged as much as possible (fig. 7). The equipment was mounted on a tree with lag bolts, which were removed when the study was completed, leaving several small, readily healable wounds.

The trail counter emits a narrow beam of invisible infrared light that bounces off a retro-reflector on the trail register (fig. 8). Interruptions in the beam activated the camera for 40-seconds, exposing one frame every 2 seconds. (The camera could be set to run up to 252 seconds and to expose one frame every 2 to 30 seconds.) The camera used 50-foot standard cartridge type color film containing 3,600 frames per roll. Exposure speed and the camera's field of view insured that few if any groups could walk on the trail without being photographed. Because the trail was fairly wide (fig. 4), there was little reason for visitors to wander off the trail and not trigger the monitoring system. This indeed was confirmed by observing groups using the trail in 1978.



MANDATORY FORM

Self-Issuing
McCORMICK PERMIT

Name ______________________

Address ______________________

City ________ State ______ Zip ______

To visit ______________________
(Name of Area)

Today's date: month ________ day ______

The time, now: ______________ am / pm

Location of entry ______________________

Location of exit ______________________

Number of people in group ______________

Number of watercraft ______________

I agree to abide by all laws, rules, and regulations which apply to this area. I will do my best to see that everyone in my group does likewise.

__________ ______________________
(Date) (Signature)

Keep the white copy in your possession while in McCormick. Please place yellow copy in slot in box.

Approved OMB No. 40-R3856

VOLUNTARY FORM

McCORMICK
REGISTRATION CARD

COMPLETE THIS CARD
AND PLACE IN SLOT IN BOX

ONLY ONE person from each group needs to complete card. Please answer ALL questions.

Name ______________________

Address ______________________

City ______________________

State ______________ Zip ________

Today's
Date: month ____________ day ________

The time, now: ______________ am / pm

Location of entry ______________________

Location of exit ______________________

Number of people in your group __________

Number of watercraft ______________

Approved OMB No. 40-R3856

Figure 6.—*Registration forms used at trail register in the McCormick Experimental Forest, 1978 and 1979.*

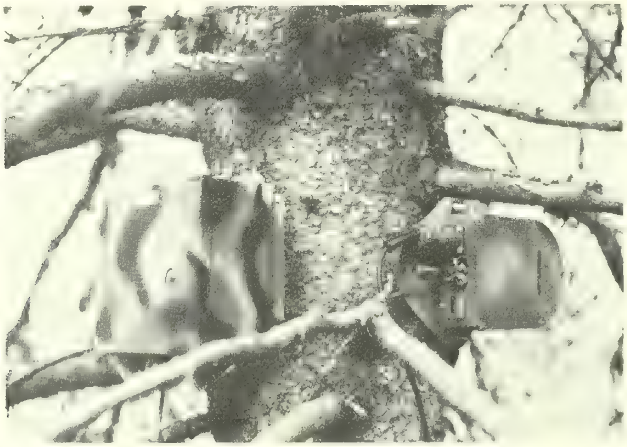


Figure 7.—*A spruce tree was used as concealment for the camera (on the left) and trail counter (on the right) used in the study.*

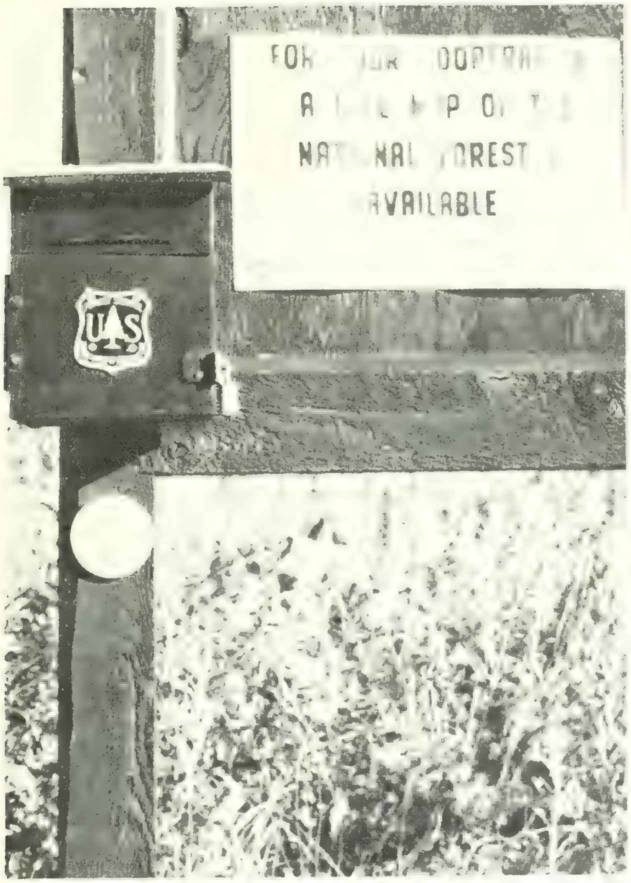


Figure 8.—*The retro-reflector used with the monitoring equipment was placed on a leg of the bulletin board under the registration box. A person walking past the trail register or stopping to register would break the invisible beam and activate the camera.*

The camera system automatically exposed one frame each hour (day **and** night) while turning on an internal red light to indicate the passage of time. This innovation is used to estimate when use occurs each day and how long people stay who enter and exit at the same location. The system ran on 12-volt batteries and was checked on Wednesdays, Saturdays, and Sundays.

In our study, a roll of film lasted about 10 days. About 3 hours were required to tabulate and analyze the information from each film. Registration forms were compared with the information on film to determine compliance or noncompliance. Comparisons were rechecked at least once to assure the reliability of results. Visitors were classified as complying with the registration requirement if they completed the necessary forms on either their way into or out of the area. (More than 95 percent of the 214 groups registering filled out the forms when they entered.)

In addition to confirming compliance and noncompliance, information was recorded from the film for all groups regarding: (1) entry hour, (2) approximate number of hours in the area (possible only for people using the same entry and exit point), (3) day of visit—weekday, Saturday, Sunday or national holiday, (4) month of visit, (5) group size, and (6) the apparent activity or activities the group pursued such as general hiking, berry-picking, fishing, hunting, and camping (even though camping is prohibited, some groups did stay overnight). This information was used to determine whether groups that registered differed from groups that did not register.

The use of cameras to monitor vehicular and recreational traffic is legal according to Forest Service legal counsel. To preserve the privacy of visitors, the camera was located far enough from the trail register that individuals could not be identified. Also, the film was viewed only by authorized personnel and destroyed after the necessary information was recorded on use patterns and registration compliance. Further, we informed administrators of the Ottawa National Forest that such information would not be made available to them as evidence against persons suspected of violating regulations of the McCormick Experimental Forest.

A field observer monitored the system during most of August 1978 and July 1979 to evaluate the equipment effectiveness and to compare actual use with the information on film. In July 1979, the observer solicited opinions of people from 12 groups about the self-registration procedures. Although this was not a primary objective of the study and the sample was not representative of all Forest visitors, their responses gave some insight regarding self-registration as a means of collecting recreational use information.

RESULTS AND DISCUSSION

Performance of Equipment

As the study began we suspected that the mandatory requirement might antagonize some people and lead to retaliatory vandalism of the bulletin board register or the use monitoring equipment. However, there was no vandalism of any kind. Locating the register uptrail from, and out of sight of, the main road and parking lot may have helped prevent vandalism (fig. 4). At least 10 groups found the equipment, but no one disturbed it. In fact, two groups left notes of inquiry attached to the equipment. In future applications we suggest an inconspicuous note be attached to the use monitoring equipment explaining what the equipment is, its purpose, and whom to contact for further information.

The monitoring equipment and the trail register performed almost faultlessly. Although it was time-consuming and required two people to line up the trail counter and the retro-reflector, once in place the system worked well. It should be noted, however, that if the counter is mounted on a tree trunk with lag bolts, as was done in this study, the counter will shift slightly within the first day or two as a natural response to the wound (fig. 7), necessitating realignment of the counter and reflector. Once this realignment was done there were no further problems.

We also experienced some inconvenience when wind caused the limbs of the spruce tree in which the camera and counter were located to activate the equipment. This was the result of the equipment placement and not of the equipment itself. Overall the effect was small, and less than 10 percent of the film was "lost" on any given roll.

Our study originally intended to use the equipment during late fall and winter to study cross-country skiers. However, at temperatures below 10°F the equipment functioned sporadically. Below zero, the equipment ceased to function. We did not experiment with different power sources or lubricants that may have facilitated cold weather operation.

During the study period, 324 groups were recorded as visiting the Forest—57 percent came when the self-issued voluntary registration requirement was in effect; 43 percent when the mandatory requirement was used.

Overall Compliance

Overall, we judged unstaffed trail registers to be effective in securing information about trail use of the McCormick Experimental Forest. Both the self-issued voluntary and the self-issued mandatory registration approaches elicited high compliance. Seventy percent of the groups entering the area under the self-issued voluntary requirement complied and the mandatory approach requirement elicited a 61 percent compliance rate.

Factors Influencing Compliance

Time of day the visit began

Generally, the time of day visits began was not related to registration compliance, except after 6 pm when visitation (4 percent of visits) and compliance (30 percent) both were low. However, in comparing the two registration forms—voluntary and mandatory—there was a significant difference ($p<0.05$) in compliance depending on the time of day the visit began (table 1). When the voluntary form was used, the rate of compliance was fairly stable throughout the day with the mid-day period—noon to 2 pm—having the highest compliance rate. When the mandatory registration form was used, the compliance rate was low in the morning (7 to 12 am) and the afternoon (2 to 6 pm), but during the mid-day period it was similar to the rate for the voluntary form. After 6 pm there was a precipitous drop both in visits and in compliance regardless of the approach used.

Because registration compliance was highest during the mid-day period when there were more people present, we believe the perceived forces of "peer pressure," whether real or imaginary, induced people to comply. This contention receives further support because groups arriving after 6 pm, when few groups are present, tended to comply at a lesser rate. Also, the likelihood of management personnel being present to check for violators was greater during the mid-day period and people may, therefore, have felt more obliged to register.

Length of stay

In general, length of stay was not statistically related to compliance. On the average each group

Table 1.—*Registration compliance by time of day group entered the McCormick Forest under voluntary and mandatory registration requirements, 1978-1979*

Type of registration requirement	Time of day									
	7 am to 12 noon		12 noon to 2 pm		2 pm to 6 pm		After 6 pm		Totals	
	Observed	Registered	Observed	Registered	Observed	Registered	Observed	Registered	Observed	Registered
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Voluntary	65	69	70	74	45	71	4	0	184	70
Mandatory	55	56	51	72	26	58	8	25	140	61
Total	120	63	121	74	71	66	12	17	324	66

stayed in the Forest 3 hours. However, those identified on the film as hunters remained longer than other people, averaging about 3½ hours. Among hunters there was a statistical relation between compliance and length of stay ($p<0.05$). Hunting groups that registered stayed in the Forest an average of 3 hours and 45 minutes, whereas hunting groups that did not register stayed, on the average, 3 hours.

Season of visit

During the spring (May) and fall (September and October) visitors were less likely ($p<0.05$) to register than were summer visitors (table 2). Slightly more than half the spring (58 percent) and fall (57 percent) visitors complied compared to nearly three-fourths of the summer visitors (72 percent).

The seasonal patterns of registration under the two approaches were similar during spring and summer, but differed significantly during the fall. In fall, the voluntary form elicited a 69 percent response compared with only 45 percent for the mandatory approach (table 2).

There are two plausible reasons for the differences in seasonal compliance. First, spring and fall compliance rates may be lower because the number of visitors are comparatively low and groups present may not perceive the need for registration. The lack of people also may lessen the chance that "peer pressure" will influence registration compliance. And, the lack of management personnel during these lower use periods may give some visitors the feeling that if they do not register there will be little chance of being caught. Second, registration compliance rates may be lower in spring and fall because during these periods many recreationists tended to be alone or in groups of two. The lower compliance rate for small groups and lone individuals may be partly explained because many of these people made short visits (shorter than the average for all groups) and perhaps believed registration was not really necessary.

Size of group

The size of the group was statistically related to registration compliance. Eighty-nine percent of the groups with more than four people registered compared to 60 percent of the groups containing less than four people (table 3). The average size of groups registering was 3.5 and those not registering was 2.5 ($p<0.05$). Again, the presence of other people (especially other group members) may have contributed to

Table 2.—*Registration compliance by season for groups visiting the McCormick Forest under voluntary and mandatory registration requirements, 1978-1979*

Type of registration requirement	Seasons							
	Spring (May 22-31,1979)		Summer (Aug 1978 and June, July, Aug 1979)		Fall (Sept 1978, Sept, Oct 1979)		Totals	
	Observed	Registered	Observed	Registered	Observed	Registered	Observed	Registered
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Voluntary	17	59	106	73	61	69	184	70
Mandatory	2	50	82	72	56	45	140	61
Total	19	58	188	72	117	57	324	66

Table 3.—*Registration compliance by group size for groups visiting the McCormick Forest under voluntary and mandatory registration requirements, 1978-1979*[1]

Type of registration requirement	Number of people per group							
	1 to 3 people		4 to 6 people		7 or more people		Total	
	Observed	Registered	Observed	Registered	Observed	Registered	Observed	Registered
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Voluntary	122	63	38	87	17	100	177	72
Mandatory	107	56	26	81	3	100	136	64
Total	229	60	64	84	20	100	313	67

[1] The numbers and percents do not equal total study numbers and percents because the exact size of eleven groups could not be determined.

a higher compliance rate for larger groups. These findings are similar to results from other studies which revealed larger groups tend to register more than smaller groups (Lucas 1975, Lucas *et al.* 1971, Wenger 1964).

Dominant recreation pursuit

Most visitors to the Forest appeared to be hikers. Although camping was not permitted, 7 percent of the groups were identified as staying one or more nights. Interestingly, 31 percent of these camping groups registered and correctly indicated an illegal length of stay!

Other than campers, hunters were the only group easily identified from the film: they represented 9 percent of the visitors. Fewer hunters—48 percent —registered than other recreationists—63 percent ($p<0.05$). Wenger (1964) and Lucas (1975) also found hunters registered less frequently than other recreationists.

Visitor Reaction to Registration Requirements

We asked 12 groups what they thought of the requirement to register before entering the area. Of the groups approached, nine were compliers and three were noncompliers. The compliers were favorable toward registration and believed information on visitor use was necessary to manage the Forest. When noncompliers were asked why they had not registered, two said they had not planned on walking the full length of the trail and felt registration was not necessary. The third group offered no specific reason for not registering.

When asked how the registration system could be improved, five of the groups said they felt an explanatory sign indicating the **purpose** of registration, as well as the **intended use** of the information obtained, would encourage greater compliance. Wenger's (1964) study reinforces this point; he found the most effective sign used on a trail registration station included a short reason for registering.

Management Implications

Unstaffed trail registers can be effective

Unstaffed trail registers can be effective in securing information from trail recreationists. But, before installing trail registers, resource administrators should have a clear understanding of their needs for information about visitor use and how such information will be used. To collect information without clear objectives unnecessarily burdens both the recreating public and recreation administrators. If it is decided that the information is essential to the management of the area, collecting it at unstaffed trail registers has certain advantages. Such a system maybe cheaper to maintain and administer than requiring visitors to go to a central location—visitor center or ranger station—and it is more convenient for the visitors themselves. And, according to our findings, it works. These contentions are supported by our findings and those of other researchers (Wenger and Gregerson 1964, Lucas *et al.* 1971, Godin and Leonard 1977).

If managers are considering using unstaffed trail registers to secure information on recreation use, we suggest they consult reports by Wenger (1964), Lucas (1971), Lucas and Kovalicky (1981), Echelberger *et al.* (1981), and Leonard *et al.* (1980) for information on trail register design, location, wording of signs, types of registration cards, and facility maintenance.

We strongly recommend registers be located up the trail, away from the trailhead and parking area. Such a location is removed from the confusion often associated with these places and from the nontrail users who could wander into the parking area and vandalize the equipment. We further recommend that trail registers be regularly and carefully serviced. Not only does the visitor need all the materials to properly register, but a well maintained facility suggests to the visitor that the registration requirement is viewed by the agency as an important, high priority activity.

Voluntary or mandatory registration: which to use?

Both the voluntary and the mandatory requirement can be successful. However, although the selection of the approach should be tied to area management objectives, we recommend using the voluntary approach where feasible. We feel that the response to the nonauthoritarian approach in our study was better because it was less obtrusive. The more solicitous the approach, the better it may fit with peoples' ideas of enjoying the out-of-doors for the sense of "freedom" it affords. If the voluntary approach is used we suggest the system be monitored regularly for compliance information.

If the mandatory approach is selected, particularly in designated Wilderness areas where accurate, reliable information maybe needed to implement visitor use limits and/or redistribution programs, we strongly suggest the agency periodically monitor compliance. If recreationists perceive the mandatory requirement as not being enforced, the tendency may be not to register. This may be especially true in areas where there is a large amount of repeat use.

Some ways to improve registration compliance

Registration compliance, regardless of approach selected, probably can be increased by judiciously scheduling patrol and maintenance services. We found compliance was notably lower in the morning and late afternoon than at mid-day. In general, compliance was greater when visitors were more numerous. We suspect that "peer pressure" induces people to register. We further believe that if patrols and other management functions were scheduled during lower use periods the mere presence of uniformed or identifiable management personnel might have a positive effect on registration rates.

Getting visitors to recognize and appreciate the importance of registration should increase registration compliance, too. Signs informing people **why** registration is needed seem especially important. Generally, the wording of signs and other instructions should be presented to appeal to people with diverse reasons for visiting the area. However, during periods when one type of use or visitor type dominates, registration requirements may need to be directed specifically to that group. For example, in our study and in others (Wenger and Gregerson 1964) getting hunters to register was a special problem. We know hunters traditionally have been responsive to wildlife management requirements, including regulations and fees. Perhaps an appeal to hunters pointing out the value of registration information to wildlife management might be effective in eliciting higher compliance rates.

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Presents findings from a study in Michigan's Upper Peninsula to evaluate the effectiveness of unstaffed trail registration stations to obtain recreation use information. Two registration approaches were evaluated: (1) self-issued voluntary registration form, and (2) self-issued mandatory registration form. The paper also cites factors influencing registration compliance and gives implications for management.

KEY WORDS: Self-registration, recreation use management, remote sensing.

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Forest Service

North Central Forest Experiment Station

Research Paper NC-215

Projecting Treatment Opportunities for Current Minnesota Forest Conditions

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W. Brad Smith and Pamela J. Jakes

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

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1981

PROJECTING TREATMENT OPPORTUNITIES FOR CURRENT MINNESOTA FOREST CONDITIONS

W. Brad Smith,
Associate Mensurationist,
and **Pamela J. Jakes,**
Associate Resource Analyst

Resource evaluation is a continuing task required by the Forest and Rangeland Renewable Resources Planning Act of 1974 (P.L. 93-378). One objective of the Act is the evaluation of timber management opportunities. In partial fulfillment of this objective, treatment opportunities were analyzed for projected Minnesota forest conditions in the decade 1977-1986. Three treatments were considered: (1) final harvest, (2) timber stand improvement (t.s.i.—consisting of commercial and noncommercial thinning or cull tree removal), and (3) stand conversion or restocking. Stand conditions were compared to treatment criteria, and the area qualifying for each treatment during the decade was determined. Volumes occurring on potential harvest and t.s.i. areas were calculated, and represent the volumes that could be expected if the treatments were carried out. **There is no correct or single estimate of the area qualifying for treatment, rather acreage varies according to the treatment criteria specified. This paper presents just one of many possible management scenarios for Minnesota's forests but conforms to generally accepted silvicultural practices.**

ASSUMPTIONS

Three major assumptions were made: (1) the area of commercial forest land would remain stable for the decade 1977-1986, (2) all commercial forest land is available for treatment, and (3) markets exist for all species and products. **The analysis did not consider possible economic, social, or political constraints on timber management.**

It was also assumed desirable to evenly distribute acreage by age class within each forest type by the end of one rotation, and that an equal area would be cut every decade of the rotation. Treatment opportunities were projected for a 10-year period, after which time they should be reassessed in light of changes in forest type area, forest management practices, and management objectives.

METHODS

Three broad treatment categories were identified for Minnesota: (1) final harvest, (2) timber stand improvement (t.s.i.—thinning or cull tree removal), and (3) stand conversion or restocking. Harvest cuts are final cuts followed by artificial or natural regeneration. Thus it was not necessary to include harvest acreage in the category stand conversion or restocking.

The logic used to assign treatments to each forest inventory plot is diagrammed in figure 1. The process is described in detail below:

(1) **Identify areas for harvest**

Treatment criteria (table 1) were used in an area control algorithm to calculate harvest acreage by Forest Survey Unit for each forest type for the decade 1977-1986 such that acreage would be evenly distributed among age classes by the end of one rotation, and an equal area would be cut during every decade of the rotation. Rotation ages for each forest type generally vary depending on management objectives. Again we emphasize that the set of harvest criteria used in this report is just one of many options possible.[1]

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[1] *For a more detailed discussion of harvest options for northern Minnesota, see: Jakes, Pamela J., and W. Brad Smith. 1980. Predicted yields from selected cutting prescriptions in northern Minnesota. U.S. Department of Agriculture Forest Service, Research Paper NC-188, 29 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.*

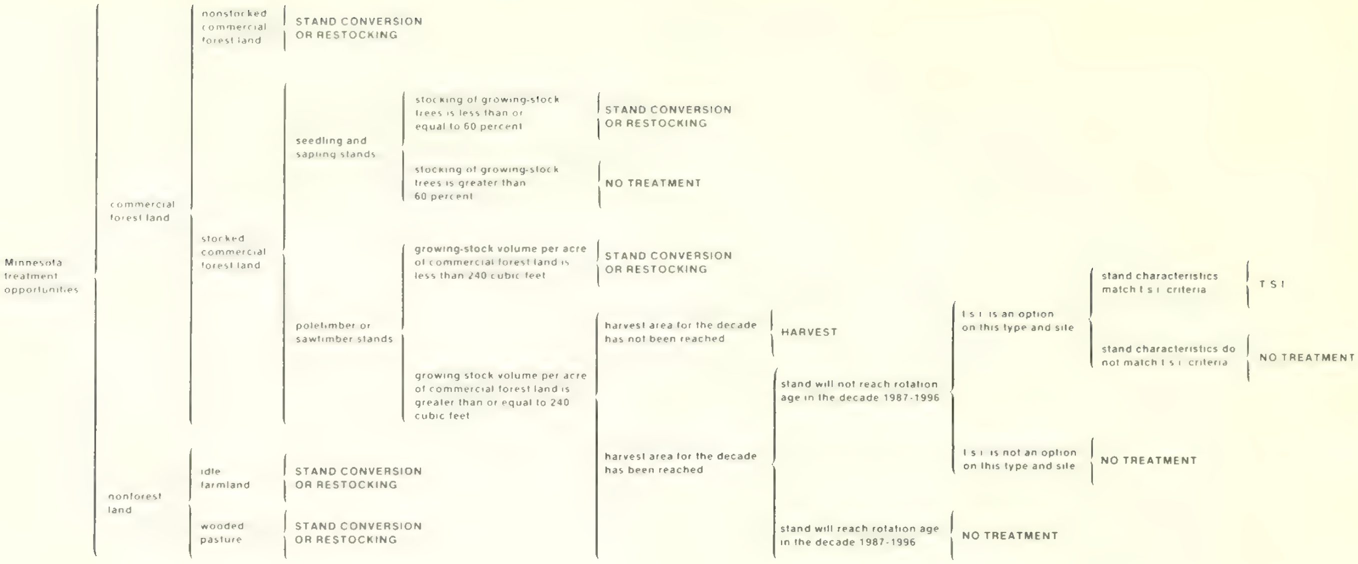
Minnesota treatment opportunities
commercial forest land
nonstocked commercial forest land
STAND CONVERSION OR RESTOCKING
stocked commercial forest land
seedling and sapling stands
stocking of growing-stock trees is less than or equal to 60 percent
STAND CONVERSION OR RESTOCKING
stocking of growing-stock trees is greater than 60 percent
NO TREATMENT
poletimber or sawtimber stands
growing-stock volume per acre of commercial forest land is less than 240 cubic feet
STAND CONVERSION OR RESTOCKING
growing stock volume per acre of commercial forest land is greater than or equal to 240 cubic feet
harvest area for the decade has not been reached
HARVEST
harvest area for the decade has been reached
stand will not reach rotation age in the decade 1987-1996
t.s.i. is an option on this type and site
stand characteristics match t.s.i. criteria
T.S.I.
stand characteristics do not match t.s.i. criteria
NO TREATMENT
t.s.i. is not an option on this type and site
NO TREATMENT
stand will reach rotation age in the decade 1987-1996
NO TREATMENT
nonforest land
idle farmland
STAND CONVERSION OR RESTOCKING
wooded pasture
STAND CONVERSION OR RESTOCKING

Figure 1.— *Logic used in assigning forest inventory plots to treatment categories, Minnesota, 1977-1986. The oldest stands in each forest type-site index range are processed first.*

Because treatments would occur throughout the 10-year period, an estimate of the average annual volumes removed during the treatment must reflect the growth that would occur on plots between 1977 (when the data were collected) and the time of treatment. For this reason, it was necessary to project each plot's growth for 5 years as an estimate of average growth for the decade. To accomplish this, plot growth from the 1977 Minnesota Forest Inventory was projected by a modified version of the Tree Growth Projection System of the Forest Resources Evaluation Program (FREP).[2] Seedling and sapling stands, nonstocked commercial forest land, and commercial forest plots with less than 240 cubic feet of growing-stock per acre were not projected by the System. The System "grew" each plot for 5 years, calculating areas and volumes represented by the plots. Because a shift in commercial forest area between stand-age classes occurred on some plots during the projection, the resulting area treated in a stand-age class cannot be directly compared to the area in the stand-age class as reported in the 1977 Minnesota Forest Inventory.

Finally, for each forest type and site index range, plots were selected for harvest until the area "cut" equalled the recommended harvest area calculated by the area control algorithm for the decade. The System assigned the highest cutting priority to overmature stands.

(2) Identifying areas for timber stand improvement

Data from projected plots not selected for harvest were compared to t.s.i. criteria shown in table 1. Area suitable for t.s.i. was calculated and the volumes removed during t.s.i. were estimated. Any stand within 10 years of rotation age was not considered for t.s.i.

Criteria for t.s.i. came from two sources. Criteria for most forest types were reached by compromise among representatives of Minnesota's forest industries and the Department of Natural Resources. For the balsam fir, white spruce, maple-basswood, and oak-hickory forest types, criteria were obtained from management guides identified in the Appendix.

On plots selected for t.s.i., the Tree Growth Projection System assigned the highest thinning priority to cull trees, then growing-stock trees of undesirable species, and finally growing-stock crop trees. Large-diameter growing stock crop trees are favored for retention during thinning. Trees were "thinned" from the plot until the recommended basal area or other stand criteria were met.

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[2] *U.S. Department of Agriculture, Forest Service. 1979. A generalized forest growth projection system applied to the Lake States region. U.S. Department of Agriculture Forest Service, General Technical Report NC-49, 96 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.*

Table 1.--Harvest and timber stand improvement criteria[1] used in assessing treatment opportunities, Minnesota, 1977-1986

Forest type	Harvest criteria		Timber stand improvement criteria	
	Site index range	Rotation age	Basal area for thinning	Post thinning basal area
	Feet	Years	Square feet	
Jack pine	0-60 61+	50 60	120	2/3 of original basal area
Red pine	0-55 56+	100 120	120	90
White pine	0-55 56+	100 120	120	90
Balsam fir	all	50	FREP guides[2]	
White spruce	all	80	FREP guides[2]	
Black spruce	0-40 41+	120 90	no thinning	
Northern white-cedar	all	100	no thinning	
Tamarack	0-40 41+	120 90	no thinning	
Oak-hickory	0-55 56+	100 80	FREP guides[2]	
Elm-ash-cottonwood	0-55 56+	70 90	100	65
Maple-basswood	all	90	FREP guides[2]	
Aspen	0-65 66+	40 60	no thinning	
Paper birch	0-65 66+	40 60	no thinning	
Balsam poplar	0-65 66+	40 60	no thinning	

[1] Management criteria agreed upon by representatives from Minnesota's forest industries and Department of Natural Resources except where otherwise noted.

[2] Guides listed in the appendix.

(3) Identifying areas for stand conversion or restocking

Areas for stand conversion or restocking were identified using the Renewable Resources Evaluation Project's data retrieval system. All sawtimber or poletimber stands with less than 240 cubic feet of growing stock per acre were recommended for conversion or restocking. Seedling and sapling stands less than 61 percent stocked with growing-stock trees also received this treatment. Other areas selected for stand conversion or restocking include nonstocked commercial forest land, idle farmland, and wooded pasture. Volume estimates on areas in the conversion and restocking treatment category represent static volumes from the 1977 forest inventory, and were not projected for the decade 1977-1986. In practice, well-stocked commercial forest land may be converted to other forest types following harvest, but this is not reflected in the treatment category.

(4) **Identifying areas requiring no treatment**

All commercial forest land not qualifying for one of the treatments discussed above received no treatment.

RESULTS
Harvest Treatment Opportunities

According to the harvest criteria outlined in table 1, 2.2 million acres of commercial forest could be harvested during the decade 1977-1986 (table 2). Nearly half of the harvest acreage is in aspen, the remaining acreage is scattered among a number of forest types.

Although all stands over 140 years old were scheduled for harvest, the majority of the harvest acreage was found in stands less than 71 years old (table 3, Appendix). Most stands more than 10 years past rotation age during the decade were harvested. However, in some forest types, for example northern white-cedar and paper birch, type acreage was so heavily concentrated in overmature stands that some stands more than 10 years past rotation age were left for harvest until the decade 1987-1996. In forest types where stands far younger than harvest age predominate, some areas were harvested before they reached rotation age.

Stands were harvested from all stand volume classes, the largest area occurring in the highest class, with at least 1,600 cubic feet of growing stock per acre (table 4, Appendix). In the red pine forest type, 89 percent of the commercial forest area selected for harvest was in the highest stand volume class. Balsam fir, on the other hand, had over half of its harvest area in stand volume classes with less than 800 cubic feet of growing stock per acre.

Average annual harvest volume of growing stock would be 281.9 million cubic feet (table 5, Appendix). Growing-stock harvest volume is concentrated in hardwood species. The average annual harvest volume from aspen species totaled 100.2 million cubic feet, more than the entire softwood harvest. While hardwood harvest volume was fairly evenly divided between poletimber and sawtimber stands (95.6 million cubic feet and 97.0 million cubic feet, respectively), softwood harvest was concentrated in sawtimber stands.

In addition to the 281.9 million cubic feet of growing stock, 29.6 million cubic feet of cull trees could be

Table 2.--Treatment opportunities on commercial forest land and nonforest land with trees by land class and forest type, Minnesota 1977-1986

(In thousand acres)

Land class and forest type	All treatments	Treatments: Harvest	T.S.I.	Stand conversion or restocking	No treatment
COMMERCIAL FOREST:					
Jack pine	507.1	94.0	8.2	19.2	385.7
Red pine	246.9	23.2	13.7	7.8	202.2
White pine	65.6	5.9	3.7	3.1	52.9
Balsam fir	867.5	166.6	19.0	58.1	623.8
White spruce	79.2	10.0	6.1	12.4	50.7
Black spruce	1,072.8	85.0	--	146.4	841.4
Northern white-cedar	502.2	46.3	--	52.2	403.7
Tamarack	482.2	44.0	--	114.8	323.4
Oak-hickory	902.9	98.5	115.5	59.1	629.8
Elm-ash-cottonwood	755.7	93.8	--	99.1	562.8
Maple-basswood	1,288.2	139.5	--	91.8	1,056.9
Aspen	5,361.6	1,074.3	--	504.7	3,782.6
Paper birch	1,006.7	224.9	--	53.3	728.5
Balsam poplar	556.5	116.9	--	94.5	345.1
Subtotal	13,695.1	2,222.9	166.2	1,316.5	9,989.5
NONFOREST:					
Idle farmland	55.0	--	--	55.0	--
Wooded pasture	135.0	--	--	135.0	--
Subtotal	190.0	--	--	190.0	--
All classes	13,885.1	2,222.9	166.2	1,506.5	9.989.5

removed annually from the harvest area. Short-log trees account for the majority of the cull tree harvest volume. For most species, cull tree volume did not contribute significantly to the total harvest volume for the species. An exception was hard maple where 43 percent of the harvest volume was in cull trees, as compared to 9 percent for all species.

The aspen forest type, with 48 percent of the harvest area, provided 59 percent of the average annual harvest volume (table 6, Appendix). More than 70 percent of the hardwood harvest volume was found in the type. Significant percentages of the harvest volumes of several softwood species were also found in aspen stands. Fifty-nine percent of the white spruce, 54 percent of the white pine, and 47 percent of the balsam fir harvest volumes were in the aspen forest type.

Timber Stand Improvement Treatment Opportunities

Following the criteria outlined in table 1, t.s.i. would occur on 166,200 acres of commercial forest land during the decade (table 2). Most (69 percent) of the t.s.i. work would occur in the oak-hickory forest type, where many 31- to 50-year-old stands were overstocked and would benefit from thinning or cull tree removal (table 7, Appendix).

Half of the timber stand improvement acreage was in stand-volume classes with at least 1,200 cubic feet of growing stock per acre (table 8, Appendix). Only in the oak-hickory forest type was t.s.i. acreage found in the lowest stand volume class (240 to 399 cubic feet of growing-stock per acre).

The average annual volume removed during t.s.i. operations over the decade would be 5.1 million cubic feet—3.8 million cubic feet in growing stock (table 9, Appendix). Aspen and balsam fir accounted for the majority of the t.s.i. growing-stock volume. For most species, more volume was removed in poletimber size trees than sawtimber size trees during t.s.i. operations. Exceptions to this included white pine, white spruce, and tamarack.

Cull trees accounted for more than one-fourth of the total average annual volume removed during t.s.i. operations. In the oak species, cull removals from t.s.i. were greater than growing-stock removals. Rough and rotten trees account for a larger portion of the cull volume than short-log trees.

Timber stand improvement growing-stock volume, like area, is concentrated in the oak-hickory forest type (table 10, Appendix). Balsam fir, white spruce, and white pine forest types accounted for most of the remaining volume.

Stand Conversion or Restocking Opportunities

Nearly 10 percent of Minnesota's 1977 commercial forest area would undergo stand conversion or restocking during the decade under the treatment criteria used in this study (table 2). An additional 190,000 acres of nonforest land would be converted to commercial forest land.

The largest portion of the commercial forest land in this treatment category was in the aspen forest type (table 11, Appendix). Over half of the commercial forest acreage selected for stand conversion or restocking was in stands less than 21 years old. The few stands over 80 years selected for stand conversion or restocking were poletimber or sawtimber stands with less than 240 cubic feet of growing-stock volume per acre.

Volume on commercial forest land selected for stand conversion or restocking totaled 237.3 million cubic feet—146.9 million cubic feet in growing stock, 90.4 million cubic feet in cull trees (table 12, Appendix). Cull volume exceeded growing-stock volume on commercial forest land in this treatment category for several species groups. The largest portions of the growing-stock and cull volumes were found in the aspen species.

Although the aspen forest type accounted for 38 percent of the commercial forest area in the treatment category, the type had 44 percent of the growing-stock volume (table 13, Appendix). The 44.9 million cubic feet of softwood volume were concentrated in the tamarack, aspen, and black spruce forest types. Most of the hardwood growing-stock volume was in the aspen forest type.

No Treatment

Under the treatment criteria specified, 10.0 million acres of commercial forest land (73 percent) would receive no treatment during the decade (table 2). In most forest types, at least 70 percent of the type acreage would receive no treatment. Exceptions included balsam poplar (62 percent), white spruce (64 percent), and tamarack (67 percent) forest types. The majority of the commercial forest area receiving no treatment was in stands less than 51 years of age (table 14, Appendix).

DISCUSSION

According to the criteria outlined earlier, 3.7 million acres of commercial forest land and 190,000 acres of nonforest land would require some forest treatment during the decade 1977-1986.

There are many reasons why these treatments may not be carried out. Wood production may not be a priority for some land owners. These owners may consider timber management incompatible with their objectives. Traditional markets may not exist for some of the products removed during treatment; however, with increasing interest in wood biomass for energy and other new products, new markets may open up. Physical features (i.e., physiographic class, slope, stand area, distance to transportation systems) may make some sites uneconomical. Administrative regulations may limit treatment options in other areas. For these reasons, the acreage recommended for various treatments in this report is a biological maximum, given the treatment criteria and current Minnesota forest conditions. Forest managers and planners can use their knowledge to temper these findings to fit local resource conditions.

The most common treatment during the decade would be harvest operations on 2.2 million acres or 16 percent of commercial forest land during the decade. In several forest types, at least 20 percent of the commercial forest area of the type would be harvested under the criteria specified—these include aspen (20 percent), balsam poplar (21 percent), and paper birch (22 percent). Data were collected during the fourth Minnesota forest inventory on plots outside the National Forests describing treatments occurring since 1962. The data indicate that only 0.7 percent of the non-National Forest commercial forest land was harvested annually. The findings of this study recommend harvesting 1.6 percent of all commercial forest land annually, over twice that found on the non-National Forest land.

As indicated earlier, some stands more than 10 years past rotation age were not harvested. This action was necessary to achieve the area control objectives—an even area distribution among age classes within a forest type by the end of one rotation, and harvest of an equal area during every decade of the rotation. In other forest types, stands were harvested as much as 50 years before rotation age so that the area control objectives could be achieved. Harvesting these "undermature" stands was not perceived as a major problem because the rotation ages in table 1 are compromise rotation ages; in actual practice, harvest often takes place at ages far below those chosen in this study. The acres cut by the System in the younger age classes fall within the lower limits. Also, in the forest types where stands are harvested below the rotation ages specified in table 1, a market exists for the products.

Timber stand improvement work in the oak-hickory forest type would occur on 65 percent of the type acreage in the 31- to 40-year age class and 52 percent of the type acreage in the 41- to 50-year age class. This relatively heavy t.s.i. work in the oak-hickory forest type reflects the belief of forest managers that the greatest individual tree growth in oak-hickory stands is obtained at the lower limits of stocking for full site utilization.[3]

Most (60 percent) of the 1.5 million acres targeted for stand conversion or restocking is commercial forest land in seedling and sapling stands less than 61 percent stocked with growing-stock:

Commercial forest land:	**Area qualifying for stand conversion or restocking**
	Acres
Seedling and sapling stands	904,800
Poletimber and sawtimber stands	242,300
Nonstocked commercial forest land	169,400
Subtotal	1,316,500
Nonforest land:	
Wooded pasture	135,000
Idle farmland	55,000
Subtotal	190,000
Total	1,506,500

In all forest types, with the exception of northern white-cedar, the majority of the area selected for stand conversion or restocking is in seedling and sapling stands (table 15, Appendix). In the northern white-cedar forest type, 68 percent of the area in the treatment category is in poletimber or sawtimber stands with less than 240 cubic feet per acre.

The assumptions and treatment criteria in this study were necessarily broad. However, by using other available inventory data, assumptions and criteria can be tightened to reflect more closely those of a particular user or region. As an example, more detailed inventory data drawn from the Project's data retrieval system indicates that a large portion of the area selected for stand conversion or restocking may be inoperable.

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[3] *Sander, Ivan L. 1977. Manager's handbook for oaks in the North Central States. U.S. Department of Agriculture Forest Service, General Technical Report NC-37, 35 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.*

The average site index of stands selected for stand conversion or restocking is 48, approximately 16 percent lower than the average site index of stands in all other treatment categories:

Site index class	Commercial forest land selected for stand conversion or restocking	Commercial forest land in all other treatment categories
	Thousand acres	
0-20	38.2	85.0
21-30	140.0	664.8
31-40	230.9	1,160.9
41-50	331.5	2,143.5
51-60	279.0	3,171.4
61-70	207.5	2,884.8
71-80	76.1	1,643.0
81-90	10.5	556.6
91 +	2.8	68.6
All classes	1,316.5	12,378.6

A larger portion of the stands in the low site index classes were recommended for stand conversion or restocking than the high site index classes. In site index class 0-20, 31 percent of the acreage qualified for stand conversion or restocking; in class 21-30, 17 percent qualified. At the other end of the site index scale, 2 percent of the commercial forest area in site index class 81-90 would undergo stand conversion or restocking, 4 percent in site index class 91 + . Low site index ratings may mean that it would not be feasible to expend large amounts of time or money managing the current forest type, but the site could be more fully utilized by another type.

Stand conversion or restocking opportunities average 26 acres in size, with 63 percent of the area in homogeneous forest blocks less than 10 acres of the same forest type, size of timber, and density. The average stand area of commercial forest land in all other treatment categories is 50 acres. This may indicate that some stands selected for stand conversion or restocking are too small in area to be economically treated individually.

Stand area class	Commercial forest land selected for stand conversion or restocking	Commercial forest land in all other treatment categories
	Thousand acres	
1-4	550.5	2,968.6
4-9	279.0	2,584.0
10-19	200.8	2,303.9
20-39	118.3	1,796.3
40-79	70.1	948.4
80-159	66.4	1,094.1
160-319	15.2	265.3
320-639	9.6	142.8
640 +	6.6	275.2
All classes	1,316.5	12,378.6

Ideally, the removal of timber volume from stands selected for stand conversion or restocking could help defray some of the management costs. However, the total volume occurring on these lands averages 180 cubic feet per acre, with growing-stock volume per acre only 112 cubic feet.

Nonforest areas targeted for restocking include 55,000 acres of idle farmland and 135,000 acres of wooded pasture. Between 1962 and 1977, only 19,600 acres of nonforest land were converted to commercial forest land outside the National Forests. Wooded pasture is area sufficiently stocked with timber to be classified as commercial forest land, but the primary land use is grazing rather than wood production. In many instances, restricting cattle or other grazers from the wooded pasture would allow regeneration to prosper, resulting in adequately stocked commercial forest land.

Wooded pasture is concentrated in the Central Hardwood Unit and is occupied primarily by hardwood forest types:

Forest type	Area of wooded pasture
	Acres
White pine	3,500
Oak-hickory	30,700
Elm-ash-cottonwood	21,800
Maple-basswood	26,900
Aspen	34,300
Paper birch	7,900
Balsam poplar	9,900
Total	135,000

Wooded pasture sites range from site index 35 to site index 75, with the following distribution among site index classes:

Site index class	Area of wooded pasture *Acres*
31-40	23,800
41-50	44,300
51-60	32,700
61-70	30,700
71-80	3,500
Total	135,000

The idle farmland selected for stand conversion or restocking is farmland that has not been tended within the last 2 years but is less than 16.7 percent stocked with all live trees. Idle farmland is most common in the Aspen-Birch and Northern Pine Forest Survey Units.

In many cases, this type of more detailed inventory data is available at cost to the public, however personnel time constraints may make the request turn-around time lengthy.

APPENDIX

MANAGEMENT GUIDES USED IN FREP AND APPLIED TO T.S.I. AREA ESTIMATES[4]

Balsam fir	U.S. Forest Service. 1967. Silvicultural practices handbook. Chapter 100—spruce-fir type.
White spruce	U.S. Forest Service. 1967. Silvicultural practices handbook. Chapter 100—spruce-fir type.
Maple-basswood	Tubbs, Carl H. 1977. Manager's handbook for northern hardwoods in the North Central States. U.S. Department of Agriculture Forest Service, General Technical Report NC-39, 29 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota. Godman, Richard M. Research forester, North Central Forest Experiment Station, Rhinelander, Wisconsin. Personal communication with Gary Brand, Research forester, North Central Forest Experiment Station, St. Paul, Minnesota.
Oak-hickory	Sander, Ivan L. 1977. Manager's handbook for oaks in the North Central States. U.S. Department of Agriculture Forest Service, General Technical Report NC-37, 35 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

DEFINITION OF TERMS

Land-Use Classes

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for nonforest use. Includes afforested areas. The minimum forest area classified was 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas were classed as forest if less than 120 feet in width.

Commercial forest land.—Forest land that is producing or is capable of producing crops of industrial wood and that is not withdrawn from timber utilization by statute or administrative regulation. This includes areas suitable for management to grow crops of industrial wood generally of a site quality capable of producing in excess of 20 cubic feet per acre of annual growth. This includes both inaccessible and inoperable areas.

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[4] *Brand, Gary. 1981. Simulating timber management in Lake States' forests. U.S. Department of Agriculture Forest Service, General Technical Report NC-69, 25 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.*

Noncommercial forest land.—(a) *Unproductive*—forest land incapable of yielding crops of industrial wood because of adverse site conditions, (b) *Productive-reserved*—forest land withdrawn from commercial timber use through statute or administrative regulation, or exclusively used for Christmas tree production.

Nonforest land.—Land that has never supported forests, and land formerly forested where forest use is precluded by development for nonforest uses, such as cropland, improved pasture, residential areas, and city parks. Also includes improved roads and adjoining rights-of-way, powerline clearings, and certain areas of water classified by the Bureau of Census as land. Unimproved roads, streams, canals, and nonforest strips in forest areas must be more than 120 feet wide, and clearings in forested areas must be more than 1 acre in size, to qualify as nonforest land.

Tree Classes

All live trees.—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

Growing-stock trees.—All live trees of commercial species except rough and rotten trees.

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs, each 8 feet or longer. At least 33 percent of the gross volume of the tree must be sound wood. Softwoods must be at least 9 inches d.b.h. and hardwoods at least 11 inches.

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber size, and of good form and vigor.

Saplings.—Live trees of commercial species 1 to 5 inches d.b.h. and of good form and vigor.

Seedlings.—Live trees of commercial species less than 1 inch d.b.h. that are expected to survive according to regional standards. (Examples of seedlings not expected to survive are those that are diseased or heavily damaged by logging, browsing, or fire.) Only softwood seedlings over 6 inches and hardwood seedlings over 1 foot in height are counted.

Rotten trees.—Live trees (any size) of commercial species that do not contain a merchantable 12-foot saw log or two noncontiguous 8-foot or longer saw logs, now or prospectively, because of rot (that is, when more than 50 percent of the cull volume of the tree is rotten).

Rough trees.—Live trees that do not contain at least one merchantable 12-foot saw log or two noncontiguous 8-foot or longer saw logs, now or prospectively, because of roughness and poor form, as well as all live noncommercial species.

Short-log (rough trees).—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Other Classifications

Site index.—An expression of forest site quality based on the height of a free-growing dominant or codominant tree of a representative species in the forest type at age 50.

Stand age.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal areas of all the trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Nonstocked areas.—Commercial forest land on which stocking of growing-stock trees is less than 16.7 percent.

Forest Types

A classification of forest land based upon the species forming a plurality of live-tree stocking. Major forest types in Minnesota are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include balsam fir, aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common asssociates include black spruce and northern white-cedar.)

Oak.—Forests in which northern red oak, white oak, or bur oak, singly or in a combination, comprise a plurality of the stocking. (Common associates include elm, maple, and aspen.)

Elm-ash-cottonwood.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include basswood and balsam poplar.)

Maple-basswood.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine and elm.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Balsam poplar.—Forests in which balsam poplar comprises a plurality of the stocking. (Common associates include aspen, elm, and ash.)

Timber Volume

Volume of growing-stock.—The volume of sound wood in the bole of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum of 4-inch top diameter outside bark, or to the point where the central stem breaks into limbs. Growing-stock volumes are shown in cubic feet. Conversion to cords may be accomplished by a factor of 79 cubic feet per solid wood cord.

Volume of sawtimber.—Net volume of the saw log portion of live sawtimber trees in board feet (International ¼-inch rule) from stump to a minimum 7 inches top diameter outside bark for softwoods and 9 inches for hardwoods.

Upper stem portion.—That part of the bole of sawtimber trees above the merchantable sawtimber top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Growth and Mortality

Net volume growth of growing stock.—The annual change in volume of sound wood in live growing-stock and sawtimber trees and total volume of trees entering these classes through ingrowth, less volume losses resulting from natural causes.

Net annual growth of sawtimber.—The annual change in volume of live sawtimber trees and the total volume of trees reaching sawtimber size, less volume losses resulting from natural causes.

Mortality of growing stock.—The volume of sound wood in growing-stock trees dying annally from natural causes. Natural causes include fire, insects, disease, animal damage, weather, and suppression.

Mortality of sawtimber.—The net board-foot volume of sawtimber trees dying annually from natural causes.

Table 3.--Commercial forest area qualifying for harvest during the decade 1977-1986 by forest type and stand-age class, Minnesota

(In thousand acres)

Forest type	All classes	Stand-age class (years)										
		Less than 31	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	94.0	--	--	1.0	27.9	31.7	7.8	12.2	10.7	2.7	--	--
Red pine	23.2	--	--	--	2.1	2.1	0	6.5	9.8	2.7	--	--
White pine	5.9	--	--	--	--	0.4	0.2	0	3.1	2.2	--	--
Balsam fir	166.6	--	--	0.2	28.7	80.4	35.8	9.7	9.1	2.7	--	--
White spruce	10.0	--	--	--	--	2.5	1.2	2.5	2.7	1.1	--	--
Black spruce	85.0	--	--	--	0.3	3.1	8.4	18.3	28.8	13.6	12.5	--
Northern white-cedar	46.3	--	--	--	--	--	--	--	--	--	42.2	4.1
Tamarack	44.0	--	--	--	--	1.9	3.1	--	0.7	14.2	22.9	1.2
Oak-hickory	98.5	--	--	0.3	0.4	4.4	5.6	16.2	20.3	43.7	7.6	--
Elm-ash-cottonwood	93.8	--	--	--	--	--	3.6	3.3	35.8	31.7	19.4	--
Maple-basswood	139.5	--	--	--	--	--	--	0.1	49.8	56.6	33.0	--
Aspen	1,074.3	--	--	37.7	492.3	345.2	125.0	53.2	15.0	4.5	1.4	--
Paper birch	224.9	--	--	--	4.4	94.3	72.1	40.6	8.2	5.3	--	--
Balsam poplar	116.9	--	0.5	6.6	38.5	37.5	25.3	7.1	1.4	--	--	--
All types	2,222.9	--	0.5	45.8	594.6	603.5	288.1	169.7	195.4	181.0	139.0	5.3

Table 4.--Commercial forest area qualifying for harvest during the decade 1977-1986 by forest type and stand-volume class, Minnesota

(In thousand acres)

Forest type	Total	Stand-volume class (cubic feet of growing stock per acre) 240-399	400-799	800-1199	1200-1599	1600+
Jack pine	94.0	1.1	14.5	17.1	20.7	40.6
Red pine	23.2	--	--	1.1	1.4	20.7
White pine	5.9	--	0.3	1.1	0.6	3.9
Balsam fir	166.6	45.0	42.3	37.9	17.3	24.1
White spruce	10.0	--	--	6.4	3.6	--
Black spruce	85.0	5.5	28.4	18.9	19.6	12.6
Northern white-cedar	46.3	4.0	17.9	17.6	3.9	2.9
Tamarack	44.0	6.8	20.1	10.8	6.3	--
Oak-hickory	98.5	6.3	39.9	22.0	22.7	7.6
Elm-Ash-Cottonwood	93.8	16.1	30.3	21.1	18.0	8.3
Maple-Basswood	139.5	6.0	32.0	64.4	20.0	17.1
Aspen	1,074.3	25.6	205.4	228.0	216.6	398.7
Paper birch	224.9	5.8	50.5	52.9	56.1	59.6
Balsam poplar	116.9	7.9	40.2	25.6	20.7	22.5
All types	2,222.9	130.1	521.8	524.9	427.5	618.6

Table 5.-- Average annual removals from harvest treatment opportunities by species group and tree class, Minnesota, 1977-1986

(In thousand cubic feet)

		Tree class					
		Growing stock			Cull		
Species	All classes	Total	Pole-timber	Saw-timber	Total	Short-log	Other[1]
SOFTWOODS:							
White pine	5,860	5,649	123	5,526	211	186	25
Red pine	9,906	9,842	639	9,203	64	50	14
Jack pine	14,771	14,290	2,919	11,371	481	338	143
White spruce	8,168	8,104	2,319	5,785	64	48	16
Black spruce	16,223	16,045	10,265	5,780	178	20	158
Balsam fir	22,156	21,544	13,065	8,479	612	259	353
Tamarack	4,389	4,077	2,397	1,680	312	103	209
Northern white-cedar	11,400	9,787	2,554	7,233	1,613	1,237	376
Other softwoods	42	40	20	20	2	1	1
Total	92,915	89,378	34,301	55,077	3,537	2,242	1,295
HARDWOODS:							
White oak	7,110	6,223	2,103	4,120	887	730	157
Select red oak	10,558	9,623	2,488	7,135	935	743	192
Other red oak	53	48	8	40	5	2	3
Hickory	179	168	40	128	11	10	1
Yellow birch	284	150	56	94	134	99	35
Hard maple	2,774	1,574	1,150	424	1,200	807	393
Soft maple	2,808	2,093	1,213	880	715	342	373
Ash	13,113	12,269	7,955	4,314	844	349	495
Balsam poplar	17,227	16,327	7,696	8,631	900	510	390
Paper birch	37,327	34,229	25,447	8,782	3,098	1,409	1,689
Bigtooth aspen	5,365	4,680	2,230	2,450	685	434	251
Quaking aspen	110,608	95,484	41,597	53,887	15,124	9,806	5,318
Basswood	3,813	3,224	1,663	1,561	589	338	251
Elm	6,543	5,884	1,670	4,214	659	566	93
Select hardwoods	284	232	77	155	52	36	16
Other hardwoods	413	327	168	159	86	58	28
Noncommercial species	137	--	--	--	137	--	137
Total	218,596	192,535	95,561	96,974	26,061	16,239	9,822
All species	311,511	281,913	129,862	152,051	29,598	18,481	11,117

[1] Rough and rotten cull.

Table 6.--Average annual growing-stock removals from harvest treatment opportunities by species group and forest type, Minnsesota, 1977-1986

(In thousand cubic feet)

Species	All types	Forest type Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack	Oak-hickory	Elm-ash cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar
SOFTWOODS:															
White pine	5,649	59	616	717	427	63	124	40	--	21	8	--	3,066	491	17
Red pine	9,842	584	3,662	166	226	28	63	25	--	148	--	--	3,432	1,508	--
Jack pine	14,290	10,295	34	--	137	2	143	--	16	--	--	--	3,456	188	19
White spruce	8,104	37	15	111	1,287	598	107	23	--	6	64	--	4,774	884	198
Black spruce	16,045	1,229	71	--	2,612	1	7,255	135	306	--	18	--	4,168	167	83
Balsam fir	21,544	119	200	111	5,750	102	208	68	31	11	496	55	10,066	2,999	1,328
Tamarack	4,077	--	--	--	282	1	356	83	2,812	--	17	--	196	--	330
Northern white-cedar	9,787	--	18	--	1,072	107	289	3,368	85	--	1,427	--	1,990	999	432
Other softwoods	40	--	--	--	--	--	--	--	--	17	--	6	--	17	--
Total	89,378	12,323	4,616	1,105	11,793	902	8,545	3,742	3,250	203	2,030	61	31,148	7,253	2,407
HARDWOODS:															
White oak	6,223	5	--	5	--	3	--	--	--	2,866	145	65	2,782	312	40
Select red oak	9,623	26	--	3	--	--	--	--	--	4,596	--	50	4,096	796	56
Other red oak	48	--	--	--	--	--	--	--	--	31	--	--	17	--	--
Hickory	168	--	--	--	--	--	--	--	--	82	--	--	--	86	--
Yellow birch	150	--	--	--	--	--	--	24	--	--	18	--	20	65	23
Hard maple	1,574	--	--	--	29	--	--	--	--	62	13	143	951	325	51
Soft maple	2,093	--	--	2	207	--	--	--	--	72	589	30	1,002	191	--
Ash	12,269	--	--	3	238	--	25	205	5	70	3,327	203	5,978	1,111	1,104
Balsam poplar	16,327	34	--	--	771	1	12	11	14	13	87	6	9,079	421	5,878
Paper birch	34,229	683	91	107	1,313	206	150	169	16	264	387	91	16,207	13,744	801
Bigtooth aspen	[illegible]	69	44	--	--	--	11	--	--	64	57	--	4,226	189	[illegible]
Quaking aspen	95,484	1,093	199	3	987	64	83	--	6	321	158	19	87,061	3,979	1,511
Basswood	[illegible]	4	--	--	8	--	--	--	--	381	171	47	2,033	486	94
Elm	[illegible]	9	--	--	11	--	11	7	7	375	1,407	126	2,914	[illegible]	537
Select hardwoods	[illegible]	--	--	--	--	--	--	--	--	52	77	21	74	8	--
Other hardwoods	[illegible]	16	--	--	--	--	--	--	--	33	239	12	20	--	7
Noncommercial species	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	[illegible]	1,939	334	123	3,564	274	292	416	48	9,282	6,675	813	136,460	22,193	10,122
All species	[illegible]	14,262	4,950	1,228	15,357	1,176	8,837	4,158	3,298	9,485	8,705	874	167,608	29,446	12,529

Table 7.--Commercial forest area qualifying for timber stand improvement during the decade 1977-1986 by forest type and stand-age class, Minnesota

(In thousand acres)

Forest type	All classes	Stand-age class (years) Less than 21	21-30	31-40	41-50	51-60	61-70	71-80	80+
Jack pine	8.2	--	1.4	6.8	--	--	--	--	--
Red pine	13.7	--	2.3	1.4	1.1	--	--	8.9	--
White pine	3.7	--	--	--	--	1.3	1.3	1.1	--
Balsam fir	19.0	--	--	19.0	--	--	--	--	--
White spruce	6.1	--	1.9	--	1.6	2.6	--	--	--
Black spruce	--	--	--	--	--	--	--	--	--
Northern white-cedar	--	--	--	--	--	--	--	--	--
Tamarack	--	--	--	--	--	--	--	--	--
Oak-hickory	115.5	--	--	42.5	73.0	--	--	--	--
Elm-ash-cottonwood	--	--	--	--	--	--	--	--	--
Maple-basswood	--	--	--	--	--	--	--	--	--
Aspen	--	--	--	--	--	--	--	--	--
Paper birch	--	--	--	--	--	--	--	--	--
Balsam poplar	--	--	--	--	--	--	--	--	--
All types	166.2	--	5.6	69.7	75.7	3.9	1.3	10.0	--

Table 8.--Commercial forest area qualifying for timber stand improvement during the decade 1977-1986 by forest type and stand-volume class, Minnesota

(In thousand acres)

Forest type	All classes	Stand-volume class (cubic foot volume of growing stock per acre) 240-399	400-799	800-1199	1200-1599	1600+
Jack pine	8.2	--	--	--	1.4	6.8
Red pine	13.7	--	--	--	1.1	12.6
White pine	3.7	--	--	--	2.4	1.3
Balsam fir	19.0	--	8.5	4.1	6.4	--
White spruce	6.1	--	1.9	--	--	4.2
Black spruce	--	--	--	--	--	--
Northern white-cedar	--	--	--	--	--	--
Tamarack	--	--	--	--	--	--
Oak-hickory	115.5	1.6	38.2	29.5	31.7	14.5
Elm-ash-cottonwood	--	--	--	--	--	--
Maple-basswood	--	--	--	--	--	--
Aspen	--	--	--	--	--	--
Balsam poplar	--	--	--	--	--	--
All types	166.2	1.6	48.6	33.6	43.0	39.4

Table 9.-- Average annual removals from timber stand improvement treatment opportunities by species group and tree class, Minnesota, 1977-1986

(In thousand cubic feet)

		Tree class					
		Growing stock			Cull		
Species	All classes	Total	Pole-timber	Saw-timber	Total	Short-log	Other[1]
SOFTWOODS:							
White pine	60	41	2	39	19	--	19
Red pine	61	61	52	9	--	--	--
Jack pine	160	104	63	41	56	26	30
White spruce	17	17	6	11	--	--	--
Black spruce	9	9	9	--	--	--	--
Balsam fir	844	825	701	124	19	4	15
Tamarack	35	35	--	35	--	--	--
Northern white-cedar	--	--	--	--	--	--	--
Other softwoods	12	--	--	--	12	10	2
Total	1,198	1,092	833	259	106	40	66
HARDWOODS:							
White oak	347	138	138	--	209	115	94
Select red oak	648	284	284	--	364	184	180
Other red oak	4	--	--	--	4	4	--
Hickory	31	25	25	--	6	--	6
Yellow birch	--	--	--	--	--	--	--
Hard maple	55	48	48	--	7	7	--
Soft maple	113	103	103	--	10	2	8
Ash	74	73	66	7	1	--	1
Balsam poplar	34	33	33	--	1	--	1
Paper birch	727	580	567	13	147	21	126
Bigtooth aspen	111	88	77	11	23	17	6
Quaking aspen	1,326	966	630	336	360	144	216
Basswood	248	144	132	12	104	11	93
Elm	159	154	145	9	5	5	--
Select hardwoods	43	31	22	9	12	2	10
Other hardwoods	5	5	5	--	--	--	--
Noncommercial species	7	--	--	--	7	--	7
Total	3,932	2,672	2,275	397	1,260	512	748
All species	5,130	3,764	3,108	656	1,366	552	814

[1] Rough and rotten cull.

Table 10.--Average annual growing-stock removals from timber stand improvement treatment opportunities by species group and forest type, Minnsesota, 1977-1986

(In thousand cubic feet)

		Forest type[1]						
Species	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Oak-hickory	Maple-basswood
SOFTWOODS:								
White pine	41	--	12	--	--	13	16	--
Red pine	61	--	61	--	--	--	--	--
Jack pine	104	28	--	46	--	30	--	--
White spruce	17	--	--	--	--	11	6	--
Black spruce	9	--	--	--	--	9	--	--
Balsam fir	825	--	--	--	662	163	--	--
Tamarack	35	--	--	--	--	35	--	--
Northern white-cedar	--	--	--	--	--	--	--	--
Other softwoods	--	--	--	--	--	--	--	--
Total	1,092	28	73	46	662	261	22	
HARDWOODS:								
White oak	138	3	--	--	--	--	135	--
Select red oak	284	--	--	--	--	--	284	--
Other red oak	--	--	--	--	--	--	--	--
Hickory	25	--	--	--	--	--	25	--
Yellow birch	--	--	--	--	--	--	--	--
Hard maple	48	--	--	--	--	--	48	--
Soft maple	103	--	--	--	--	--	103	--
Ash	73	--	--	--	--	--	73	--
Balsam poplar	33	--	--	--	--	23	10	--
Paper birch	580	--	6	--	--	18	556	--
Bigtooth aspen	88	--	--	--	--	--	88	--
Quaking aspen	966	8	--	119	362	139	338	--
Basswood	144	--	--	--	--	--	144	--
Elm	154	--	--	--	--	--	154	--
Select hardwoods	31	--	--	--	--	--	31	--
Other hardwoods	5	--	--	--	--	--	5	--
Noncommercial species	--	--	--	--	--	--	--	--
Total	2,672	11	6	119	362	180	1,994	--
All species	3,764	39	79	165	1,024	441	2,016	--

[1] Only the forest types listed in the table were assigned t.s.i. criteria.

Table 11.--Area of commercial forest land qualifying for stand conversion or restocking during the decade 1977-1986 by forest type and stand-age class, Minnesota

(In thousand acres)

Forest type	All classes	Stand-age class (years) 1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	19.2	7.3	5.7	3.8	2.4	--	--	--	--	--	--	--	--	--
Red pine	7.8	5.7	1.2	0.9	--	--	--	--	--	--	--	--	--	--
White pine	3.1	--	3.1	--	--	--	--	--	--	--	--	--	--	--
Balsam fir	58.1	16.6	18.9	11.6	2.7	1.7	3.3	2.0	1.3	--	--	--	--	--
White spruce	12.4	5.4	5.5	1.5	--	--	--	--	--	--	--	--	--	--
Black spruce	146.4	45.4	24.8	35.9	14.3	6.0	8.5	--	8.1	1.8	1.6	--	--	--
Northern white-cedar	52.2	3.6	5.9	5.7	--	--	1.4	4.2	5.6	3.0	5.8	8.8	8.2	--
Tamarack	114.8	29.4	38.3	15.7	9.3	4.2	4.9	3.0	4.2	1.2	--	3.4	1.2	--
Oak-hickory	59.1	19.4	14.2	6.9	3.1	1.7	3.1	6.2	1.5	1.3	1.7	--	--	--
Elm-ash-cottonwood	99.1	33.9	20.9	13.9	7.3	1.7	2.7	5.5	5.1	4.9	3.2	--	--	--
Maple-basswood	91.8	15.3	24.1	10.7	6.0	9.9	14.0	3.2	3.9	3.1	1.6	--	--	--
Aspen	504.7	228.8	134.0	74.3	34.0	17.0	14.9	1.7	--	--	--	--	--	--
Paper birch	53.3	17.0	11.2	5.8	7.5	3.1	2.1	4.4	0.8	--	--	1.4	--	--
Balsam poplar	94.5	35.4	33.0	11.7	7.2	3.0	3.4	0.8	--	--	--	--	--	--
All types	1,316.5	463.2	340.8	198.4	93.8	48.3	58.3	31.0	30.5	15.3	13.9	13.6	9.4	--

Table 12.--Growing-stock volume on stands selected for stand convesion or restocking by species and tree class, Minnesota, 1977-1986

(In thousand cubic feet)

		Tree class					
		Growing stock			Cull		
Species	All classes	Total	Pole-timber	Saw logs	Total	Short-log	Other[1]
SOFTWOODS:							
White pine	2,207	1,932	1,904	28	275	54	221
Red pine	1,815	1,693	1,468	225	122	--	122
Jack pine	6,041	4,601	1,836	2,765	1,440	206	1,234
White spruce	3,071	2,830	1,467	1,363	241	--	241
Black spruce	14,102	11,474	4,062	7,412	2,628	139	2,489
Balsam fir	12,465	9,590	3,239	6,351	2,875	467	2,408
Tamarack	16,551	10,377	3,564	6,813	6,174	380	5,794
Northern white-cedar	6,548	2,407	1,171	1,236	4,141	807	3,334
Other softwoods	281	--	--	--	281	--	281
Total	63,081	44,904	18,711	26,193	18,177	2,053	16,124
HARDWOODS:							
White oak	8,348	2,214	1,168	1,046	6,134	1,876	4,258
Select red oak	4,545	1,567	1,118	449	2,978	417	2,561
Other red oak	644	644	604	40	--	--	--
Hickory	541	514	493	21	27	--	27
Yellow birch	97	--	--	--	97	--	97
Hard maple	3,376	832	579	253	2,544	354	2,190
Soft maple	4,299	1,222	535	687	3,077	194	2,883
Ash	19,742	13,853	6,048	7,805	5,889	298	5,591
Balsam poplar	14,163	11,084	5,893	5,191	3,079	356	2,723
Paper birch	19,965	13,135	4,515	8,620	6,830	668	6,162
Bigtooth aspen	699	528	234	294	171	--	171
Quaking aspen	75,932	45,792	17,702	28,090	30,140	2,517	27,623
Basswood	2,572	1,344	520	824	1,228	292	936
Elm	13,345	7,719	3,633	4,086	5,626	2,169	3,457
Select hardwoods	791	410	331	79	381	103	278
Other hardwoods	2,991	1,176	325	851	1,815	248	1,567
Noncommercial species	2,221	--	--	--	2,221	--	2,221
Total	174,271	102,034	43,698	58,336	72,237	9,492	62,745
All species	237,352	146,938	62,409	84,529	90,414	11,545	78,869

[1] Rough and rotten cull.

Table 13.--Growing-stock volume on stands selected for stand conversion or restocking by species group and forest type, Minnsesota, 1977-1986

(In thousand cubic feet)

		Forest type													
Species	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tama-rack	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar
SOFTWOODS:															
White pine	1,932	42	--	159	339	144	77	339	--	20	--	125	687	--	--
Red pine	1,693	296	--	216	--	--	--	--	--	71	--	--	1,110	--	--
Jack pine	4,601	2,016	151	--	--	--	--	--	--	212	--	527	1,525	102	68
White spruce	2,830	90	--	--	215	115	--	238	118	319	157	251	1,022	73	232
Black spruce	11,474	--	--	82	853	--	6,188	1,277	1,673	--	--	--	1,272	--	129
Balsam fir	9,590	--	--	--	2,273	50	458	2,835	252	132	507	351	2,466	180	86
Tamarack	10,377	--	--	--	292	--	1,533	359	6,434	--	430	85	382	472	390
Northern white-cedar	2,407	--	--	--	525	--	--	770	316	--	223	--	216	195	162
Other softwoods	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	44,904	2,444	151	457	4,497	309	8,256	5,818	8,793	754	1,317	1,339	8,680	1,022	1,067
HARDWOODS:															
White oak	2,214	--	--	--	--	--	--	--	--	129	23	320	1,592	--	150
Select red oak	1,567	141	--	--	--	--	--	--	--	--	--	692	734	--	--
Other red oak	644	--	--	--	--	--	--	--	--	--	302	342	--	--	--
Hickory	514	--	--	--	--	--	--	--	--	514	--	--	--	--	--
Yellow birch	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hard maple	832	--	--	--	--	--	--	--	--	--	--	396	436	--	--
Soft maple	1,222	--	--	--	--	--	--	--	--	--	249	457	379	137	--
Ash	13,853	--	--	--	132	--	15	96	--	177	6,358	5,036	1226	122	691
Balsam poplar	11,084	--	--	--	---	--	--	--	30	--	854	79	4,751	839	4,531
Paper birch	13,135	203	--	--	580	58	191	91	339	266	140	838	6,805	3,306	313
Bigtooth aspen	528	--	--	--	--	--	--	--	--	40	115	80	293	--	--
Quaking aspen	45,792	--	--	--	570	--	790	50	322	574	675	1,424	37,875	945	2,567
Basswood	1,344	--	--	--	--	--	--	--	--	--	303	728	313	--	--
Elm	7,719	--	--	--	100	--	--	--	--	1,484	1,693	2,336	1,981	--	125
Select hardwoods	410	--	--	--	--	--	--	--	--	132	220	58	--	--	--
Other hardwoods	1,176	--	--	--	--	--	--	--	--	112	838	226	--	--	--
Noncommercial species	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	102,034	344	--	--	1,382	58	996	237	691	3,428	11,770	13,012	56,385	5,349	8,382
All species	146,938	2,788	151	457	5,879	367	9,252	6,055	9,484	4,182	13,087	14,351	65,065	6,371	9,449

Table 14.--Commercial forest area requiring no treatment by forest type and stand age class, Minnesota, 1977-1986

(In thousand acres)

Forest type	All classes	Stand-age class (years)												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	385.7	18.1	13.3	59.3	89.8	113.7	70.6	20.7	0.2	--	--	--	--	--
Red pine	202.2	4.6	37.5	8.8	26.6	18.8	14.5	13.5	38.6	15.1	24.2	--	--	--
White pine	52.9	2.1	0.2	--	1.3	8.9	2.8	8.1	7.5	3.9	14.5	3.6	--	--
Balsam fir	623.8	33.9	49.5	66.6	79.9	219.1	146.2	27.1	--	1.5	--	--	--	--
White spruce	50.7	8.8	1.7	1.4	8.2	17.2	12.0	1.4	--	--	--	--	--	--
Black spruce	841.4	33.1	78.3	138.1	150.1	111.6	121.8	69.6	64.4	42.1	28.8	3.5	--	--
Northern white-cedar	403.7	3.0	4.4	19.1	21.7	18.1	39.4	57.5	46.7	58.3	63.7	48.1	23.7	--
Tamarack	323.4	17.9	40.3	33.3	21.9	34.2	63.6	22.0	24.9	34.1	8.3	20.5	2.4	--
Oak-hickory	629.8	17.8	24.4	6.5	19.2	64.7	126.1	130.4	92.9	71.3	70.4	6.1	--	--
Elm-ash-cottonwood	562.8	30.5	30.2	33.2	32.7	76.7	117.6	83.8	61.0	65.4	31.1	0.6	--	--
Maple-basswood	1,056.9	19.3	26.7	30.5	89.9	190.6	220.3	188.3	152.3	87.8	49.2	2.0	--	--
Aspen	3,782.6	509.6	384.0	401.5	870.6	1,199.2	415.8	1.9	--	--	--	--	--	--
Paper birch	728.5	23.9	48.7	28.7	112.0	260.6	229.7	17.9	--	3.1	3.7	0.2	--	--
Balsam poplar	345.1	37.6	45.0	31.9	82.7	111.3	36.6	--	--	--	--	--	--	--
All types	9,989.5	760.2	784.2	858.9	1,606.6	2,444.7	1,617.0	642.2	488.5	382.6	293.9	84.6	26.1	--

Table 15.--Area of commercial forest land qualifying for stand conversion or restocking by forest type and tree class, Minnesota, 1977.

(In thousand acres)

Forest type	All classes	Tree class: Nonstocked	Tree class: Seedlings and saplings	Tree class: Poletimber or sawtimber
Jack pine	19.2	2.7	15.2	1.3
Red pine	7.8	--	7.8	--
White pine	3.1	--	3.1	--
Balsam fir	58.1	8.4	41.4	8.3
Black spruce	146.4	31.0	100.9	14.5
White spruce	12.4	--	12.4	--
Northern white-cedar	52.2	3.6	13.1	35.5
Tamarack	114.8	16.8	86.4	11.6
Oak-hickory	59.1	9.0	28.8	21.3
Elm-ash-cottonwood	99.1	17.6	60.0	21.5
Maple-basswood	91.8	4.3	47.0	40.5
Aspen	504.7	59.3	387.3	58.1
Paper birch	53.3	9.1	29.0	15.2
Balsam poplar	94.5	7.6	72.4	14.5
All types	1,316.5	169.4	904.8	242.3

Smith, W. Brad, and Pamela J. Jakes.

1981. Projecting treatment opportunities for current Minnesota forest conditions. U.S. Department of Agriculture Forest Service, Research Paper NC-215, 21 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Reviews opportunities for treatment of timber stands in Minnesota for the decade 1977-1986. Under the assumptions and management guides specified, 27 percent of Minnesota's commercial forest land would require timber harvest or some other form of treatment during the decade.

KEY WORDS: forest management, treatment opportunities, timber harvest.

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Forest Experiences of Fifth-grade Chicago Public School Students

Laura J. Metro, John F. Dwyer, and Erwin S. Dreschler

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

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FOREST EXPERIENCES OF FIFTH-GRADE CHICAGO PUBLIC SCHOOL STUDENTS

Laura J. Metro, *Forestry Aide,*
John F. Dwyer, *Principal Urban Forestry Specialist,*
North Central Forest Experiment Station,
Chicago, Illinois,
and **Erwin S. Dreschler,** *Teacher,*
Public School System,
Chicago, Illinois

Urban children have various amounts and types of nature-related experiences in urban and rural environments. Some camp with their families; some go on scouting expeditions or other group events; some enjoy nature at nearby parks, rivers, vacant lots, or forest preserves; and others have had little contact with natural environments.

Through a Chicago Public School Program, fifth-grade youngsters from different cultures and backgrounds were brought together to experience and learn about a forest environment. The program—Academic Interest Center for Environmental Studies (AICES)—involved sessions in an urban forest located at North Park Village which is a 155-acre heavily wooded site offering both built up and natural environments.

Children entered the program with different backgrounds and varied forest experiences. To design programs to meet the children's particular needs, the AICES staff was interested in their perceptions and expectations concerning the forest. Therefore, prior to their North Park Village visit, the children filled out a brief questionnaire about their previous forest experiences. This report is an analysis of responses to that questionnaire. The results provide insight on the experiences, perceptions, and expectations of urban children in regard to forest resources. These insights are offered here to help direct other urban education programs that focus on forests and related natural resources. Furthermore, this analysis is offered to help guide urban forest resource managers in their efforts to make use of the strong educational value of urban forests. Environmental education programs focusing on the urban forest can increase children's understanding of ecosystems and enhance their use and enjoyment of the urban forest.

LITERATURE REVIEW

Similar studies with young children are rare, however, several studies have been conducted with older children and adults. In several studies, differences were found in the recreation preferences and behavior of Blacks and Whites (Washburne 1978, Wendling 1980). These differences appear to extend to use and perception of forest resources. Peterson (1977) reported that Black and female high school students are especially attracted to urban recreation areas. Fritschen (1980) found that urban nonwhites were more likely than urban Whites to prefer slide-tape nature programs that portray plants and animals found in the city. Other differences in nature-related attitudes were suggested by Dorsey (1972) who reported that White students exhibited greater understanding and reasoning in conservation concepts than Black students. Similarly, Kellert (1979) found low naturalistic and ecologistic attitudes among Blacks. In that same study, Kellert reported that females and Blacks had more negative attitudes toward animals, including more fear of wildlife, than did White males.

METHODS

An AICES teacher distributed questionnaires to students several weeks before they attended the learning sessions at North Park Village and prior to discussion of that visit. Consequently, the responses were not influenced by the AICES program. Children from 12 Chicago schools representing a cross section of the school system were given the questionnaire. The students ranged from 9 to 11 years of age.

Ten simple and straight-forward questions were asked concerning forest experiences, perceptions, and expectations. Most were open-ended to avoid influencing responses. Respondents were categoried by gender and race (Black, White, Hispanic, and Oriental). However, the number of Hispanic and Oriental students was small so we limited the analysis to the responses of Blacks and Whites. A total of 269 questionnaires, well distributed by gender and by Black or White, were used in the analysis. The analysis of differences in forest experiences, perceptions, and expectations among the students is limited by lack of information on the children's school, family, home environment, and the accessibility of forest resources. Such information would more fully explain student responses.

RESULTS

Previous Visits to a Forest

Three-fourths of the respondents had been to a forest or woodland prior to the AICES program. As shown in the following tabulation, a significantly (0.01) higher portion of Whites (87 percent) than Blacks (69 percent) had visited a forest.

Have you ever visited a forest?

Race	**Yes**	**No**
	(Number)	
Black	105	48
White	100	15

Within each race reported forest visits did not differ significantly between males and females.

Of those students who reported going to a forest, Whites indicated a significantly (0.01) greater frequency of visits than Blacks. Less than 20 percent of the Blacks who had been to a forest stated they had visited more than five times; whereas nearly 50 percent of the Whites were in the same category.

How many times have you been to a forest?

Race	**1 to 5**	**6 or more**
	(Number)	
Black	82	19
White	48	46

Visits by males and females in either group were not significantly different (0.05).

Students who had been to a forest were asked to identify the forest by name or location. The responses ranged from names of specific places to names of towns and States so they were aggregated by States, with Illinois divided into Chicago, the suburbs, forest preserves, and others. Blacks mentioned nearby urban forest areas more frequently than Whites, which is consistent with Washburne's (1978) findings that Blacks concentrate their recreation activity in urban settings.

Where are the forests that you have visited?

Forest location	**Blacks**	**Whites**
	(Number)[1]	
Illinois		
Forest preserves	30	22
Chicago	14	13
Suburbs	0	4
Other	11	22
Wisconsin	3	17
Michigan	11	6
Other States	22	22
Respondents	89	96

Students were then asked to identify with whom they usually visit the forest. All students reported going to the forest most frequently with their families. This finding corresponds with the results of Fritschen's (1980) study of Belle Isle Nature Center in Detroit, in which 70 percent of the visitors surveyed came to the center with their families. In the present study, only one difference was apparent between races. Approximately 18 percent of the Black students reported the school as the group they usually go with to the forest, while none of the White students gave that response.

Who do you usually go with to the forest?

Group	**Blacks**	**Whites**
	(Number)[1]	
Family	65	74
Scouts	16	15
Camp	31	16
School	33	0
Friends	36	32
Respondents	105	100

This difference can be attributed, in part, to the participation of some of the Black students in a federally funded program aimed at teaching outdoor education to inner-city youths. Also, the lower visitation rate to the forest by Black children may have increased the importance of school visits.

Enjoyment of the Forest

Students who had been in a woods or forest were asked whether or not they enjoyed the experience. More than 90 percent of the respondents indicated they had enjoyed being in the forest. Response differed little by race or gender.

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[1] *Includes multiple responses.*

Students were asked why they did or did not enjoy their previous forest experiences. Although their responses were numerous and highly diverse, the most frequent responses for what they enjoyed about the forest are shown below:

Why do you like visiting the forest?

Reason for enjoying the forest	Blacks	Whites
	(Number)[1]	
Nature		
Plants	16	35
Animals	12	25
General	0	10
Activities		
Explore	16	11
Play	13	7
Picnic	5	4
Pleasing environment	13	29
It's fun	31	14
Respondents	91	96

Responses of Blacks and Whites were noticeably different. Blacks answered "it's fun" most frequently, whereas Whites answered plants and animals most frequently. Similarly, Whites frequently mentioned interest in nature and the related environment as a reason for enjoying the forest, and Blacks more frequently listed activities such as exploring and playing. These responses correspond, in part, to previous findings of lower understanding and reasoning in conservation (Dorsey 1972) and lower naturalistic and ecologistic attitudes among Blacks (Kellert 1979).

Only a few students, approximately the same proportion of Blacks and Whites, did not enjoy their forest experiences. The reasons most frequently cited were related to insects, fear of animals, fear of getting lost, and general "scariness."

Perceptions of Nonusers

As shown in the following tabulation, most of the students who had never been to a forest expected that they would enjoy such an experience.

Although you have never been to a forest, do you think you would enjoy such an experience?

	Yes	No
	(Number)[1]	
Blacks		
Males	15	3
Females	18	11
Whites		
Males	6	1
Females	7	0

Black females reported the least favorable expectations, with only 62 percent indicating they would enjoy a forest experience.

Students who had not been to a woods or forest were also asked why they thought they would or would not enjoy the experience. The most frequently mentioned reasons for perceiving enjoyment were simply that the students thought they "would like it" or because of the plants and animals. Other students reported they would like to see new things.

Out of the White students who had not been to a forest, only one male indicated that he would not enjoy a forest experience. Fourteen Black students had negative expectations of a forest—three-fourths of the negative comments were made by Black females.

It is interesting to note that Black students who had not visited a forest had expectations for the forest experience that were somewhat lower and more fear-oriented than the experiences reported by those who had visited a forest. This suggests that either a visit to the forest may alleviate such fears or that those who fear the forest did not go.

Previous Forest Experiences

When asked how they spend their time in the woods, most students reported they explore, walk, and hike. Blacks indicated more participation in sports and play activities than Whites who reported more exploration activities (table 1). White females indicated a particularly strong orientation towards exploration, and Black females indicated exploration more frequently than Black males.

The orientation of Blacks toward sports is consistent with much of the existing literature on racial/ethnic differences in recreation behavior (Wendling 1980). In this study the difference may be related, in part, to the higher reported use by Blacks of Chicago parks and Cook County Forest Preserves, which provide significant opportunities for recreation. Students frequently mentioned that they look at animals, which was also reported as a key reason for enjoying the forest experience.

Students were also asked what they learned from their previous experiences in a woods or forest. Most students reported that they learned about animals, reaffirming that animals are strongly associated with a forest experience. Fritschen (1980) stated that urban audiences prefer slide-tape programs about animals to those about plants. In the present study, Blacks reported that they learned about animals more often than Whites (table 2). All students reported that they learned outdoor skills while in the forest.

Table 1.—*How students reported spending their time in a forest*[1]
(In numbers)

Activity	Total	White Males	White Females	White Total	Black Males	Black Females	Black Total
Explore	87	18	33	51	14	22	36
Walk/Hike	59	20	14	34	10	15	25
Sports	56	19	4	23	22	11	33
Play	44	13	6	19	10	15	25
Camp	18	7	4	11	2	5	7
Observe animals	38	8	9	17	12	9	21
Observe plants	22	7	6	13	3	6	9
Enjoy outdoors	29	7	9	16	4	9	13
Respondents	203	54	46	100	46	57	103

[1] Includes multiple responses.

Table 2.—*What students reported learning in a forest*[1]
(In numbers)

Learned about in a forest	Total	White Males	White Females	White Total	Black Males	Black Females	Black Total
Nature							
Animals	59	13	10	23	13	23	36
Plants	44	18	12	30	5	9	14
General	30	11	10	21	7	2	9
Outdoor skills	49	12	11	23	15	11	26
Misc. Positive	42	15	7	22	11	9	20
Misc. Negative	8	0	1	1	1	6	7
Nothing	15	0	6	6	5	4	9
Respondents	194	51	44	95	47	52	99

[1] Includes multiple responses.

The highest frequency of negative comments about learning experiences were reported by Black females (table 2). This, plus the negative expectation of Black females who had not visited a forest, suggests that special consideration be given to this group in environmental education. Negative comments about learning experiences were also reported by White females and Black males but not by White males.

Fears

Because many children seem to have some fear of the woods (Devlin 1973, Kaplan 1976), the students were asked what they saw as a danger in the forest. As shown in the following tabulation, the most frequent response was animals and the second most frequent response was no fears.

What do you think are dangers in the forest?

Danger	Whites	Blacks
	(Number)[1]	
Animals	38	49
Nothing	18	21
Hazards	17	20
Fire	10	17
Plants	11	5
Debris	6	10
Respondents	98	105

As a frame of reference for the above question, all students, regardless of whether or not they had been to a forest, were asked what they see as a danger in their neighborhood. Most students, except Black males, most frequently reported no danger (table 3). Nevertheless, many responses of danger were reported and significant differences were found by race. Blacks reported many more types of danger than

Table 3.—*Neighborhood dangers most often identified by fifth grade students*[1]
(In numbers)

Type of danger	Total	White		Black	
		Males	Females	Males	Females
Nothing	51	21	11	6	13
Assault	40	7	7	9	17
Cars	37	9	10	8	10
Killers	26	2	4	12	8
Fire	26	1	4	10	11
Fights	24	0	1	9	14
Dogs	23	5	3	8	7
People	22	4	6	3	9
Gangs	22	6	2	8	6
Guns	21	0	2	8	11
Rats	8	0	0	3	5
Respondents	256	57	53	62	84

[1] Includes multiple responses.

Whites. Whites most frequently mentioned cars and Blacks most frequently mentioned assault. Blacks often listed fire as a danger in both the forest and their neighborhood, suggesting that fears in various environments may be related.

SUMMARY

Urban forest managers and others involved in environmental education programs for fifth-grade youngsters in Chicago can expect that most of the children: (1) have been to an urban or rural forest with their family or another group, and (2) have enjoyed and learned from the experience, which usually involved walking or hiking. Most students who have not visited a woods or forest reported that they would enjoy such an experience.

Previous forest/woodland experiences of fifth graders differ by gender and ethnic background. A larger portion of Whites than Blacks had visited the forest, and Whites also reported more visits. School groups were a more common contact with the forest for Blacks than for Whites. Blacks, particularly Black females, emphasized the "fun" and "play" aspects of the forest, whereas Whites emphasized the natural qualities. This correlates, in part, with findings in other studies of less interest in nature, conservation, and animals by Blacks and females. Black females cited the negative aspects of the forest environment and reported learning nothing from a forest experience more often than any other group. Perhaps they should be given additional orientation to the forest as part of an environmental education experience.

Most students feel safe in the forest as well as in their own neighborhood, although Blacks reported a larger number of dangers in each environment. Some evidence suggests that fears in home and forest environments are related. For example, Blacks often cited fire as a threat in both environments. And Blacks reported a significant fear of dogs and rats in their home environment. This fear may be transferred to a fear of animals in the forest.

When developing environmental education programs for fifth graders it is not enough to study only the children's reactions to the forest. We must also study their home environment to: (1) relate the education program to concepts the children can understand, and (2) comprehend children's reactions to the material being presented. An example is "Nature City" in which aspects of the forest are translated into urban concepts and language (Lewis 1975).

In this study, we emphasized urban forests. With environmental educational programs tailored to fit their backgrounds and needs urban children can develop a better understanding of the natural environment and increase their enjoyment of urban forests.

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Analyzes previous visits to a forest and the associated experiences, as well as the expectations of those who had not previously visited a forest. Recommends educational programs that focus on the urban forest.

KEY WORDS: Urban, forestry, environment, education, interpretation.

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Growth and Yield Model for the Elm-Ash-Cottonwood Type in Indiana

Stephen R. Shifley, John W. Moser, Jr., and K[illegible]

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St. Paul, Minnesota 55108
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GROWTH AND YIELD MODEL FOR THE ELM-ASH-COTTONWOOD TYPE IN INDIANA

Stephen R. Shifley, *Research Forester,*
North Central Forest Experiment Station, St. Paul, Minnesota,
John W. Moser, Jr., *Professor of Forestry,*
Purdue University, West Lafayette, Indiana,
and **Kenneth M. Brown,** *Associate Professor of Forestry,*
Lakehead University, Thunder Bay, Ontario

More than 0.5 million acres of commercial elm-ash-cottonwood forest can be found in Indiana (Spencer 1969) with an additional 1.4 million acres occurring in Illinois (Essex and Gansner 1965). The percent of commercial elm-ash-cottonwood forest land in these two States is surpassed only by that of oak-hickory. Most elm-ash-cottonwood stands occur on good to excellent sites. Despite its abundance, however, little has been published concerning the growth and yield of the elm-ash-cottonwood (E-A-C) forest type in the Central States (Shifley and Brown 1978).

This paper reports the results of a recent study of the growth and yield of the E-A-C forest type in Indiana. The study led to the development of a system of mathematical models that have been used to generate yield tables for E-A-C stands.

TYPE DEFINITION

The E-A-C forest type is defined here as any bottomland forest in which elm (*Ulmus* spp.), green ash (*Fraxinus pennsylvanica* Marsh.), cottonwood (*Populus deltoides* Marsh.), silver maple (*Acer saccharinum* L.), or red maple (*Acer rubrum* L.), singly or in any combination, comprise a plurality of the stocking. Willow (*Salix nigra* Marsh.), boxelder (*Acer negundo* L.), and sycamore (*Platanus occidentalis* L.) are common associates. Although the E-A-C species mixture inhabits a variety of poorly drained upland sites, only occurrences of the type adjacent to waterways were considered in this study.

DATA

Remeasurement data were collected in 1977 from 35 continuous forest inventory (CFI) sampling units located in Indiana E-A-C stands of natural origin.[1] Each sampling unit was comprised of 10 subsamples equally spaced over approximately 1 circular acre. At each subsample point trees greater than or equal to 5 inches d.b.h. were sampled using a 37.5 factor prism. Trees between 1 and 5 inches d.b.h. were sampled on a 1/300 acre circular plot centered on the prism point. Annual ingrowth, survivor growth, mortality, and cut were estimated on a per-acre basis for each of the sampling units (table 1). These annual rates of change were used to construct the rate equations in subsequent sections.

Although pure stands of even-aged cottonwood, willow, or mixtures of these two species are classic early stages in E-A-C succession on newly-formed land, the stands encountered in the data collected for this study are characterized by mixed species and variable size classes as found in subsequent seral stages or in E-A-C development on old field sites (Hosner and Minkler 1963).

PAST WORK

Whole-stand, age-independent modeling techniques are well suited to predict E-A-C stand dynamics because such models can be calibrated with few data and for both even-aged and uneven-aged stands.

MacKinney *et al.* (1937) and Schumacher (1939) present some of the earliest mathematical forest stand growth and yield models. It was not until more recently, however, that Buckman (1962) and Clutter

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[1] *Data from Indiana State Survey were provided by the Renewable Resources Evaluation Project, North Central Forest Experiment Station.*

(1963) demonstrated that differential equations could be applied to obtain compatible growth and yield estimates for even-aged forest stands. Pienaar (1965) and Turnbull (1963) examine in detail the biomathematical aspects of growth and yield estimation in pure and mixed stands. Pienaar and Turnbull (1973) emphasize the importance of biologically reasonable growth and yield models, and they suggest the Chapman-Richards function as a suitable model for a variety of even-aged stand growth applications. While previous attempts to model stand growth using differential equations had been limited to even-aged stands, Moser and Hall (1969) extended differential equation theory to applications involving growth and yield in uneven-aged stands.

Leary (1970) suggests that systems for modeling forest stand dynamics may be separated into components, each component defined by one or more difference equations within a system of equations which, in total, describe stand growth. In such a system stand yield is determined through the simultaneous solution of the component equations. Leary gives an example in which tree size classes are the components through which stand dynamics are modeled, but he suggests that the components used to model stand dynamics will vary with the application. Moser (1972) presents a system of differential equations describing uneven-aged stand growth in which the components used are ingrowth, survivor growth, and mortality in the stand, i.e., the components of growth (Beers 1962).

Both Moser (1974) and Ek (1974) have demonstrated that more complex stand modeling systems are feasible. In separate studies involving applications with uneven-aged mixed hardwoods, each author models stand growth by dividing the stand into a number of component size classes. Growth within each size class is further separated into expressions for ingrowth, survival growth, mortality, and upgrowth. Moser uses a system of 66 equations (11 equations for each of 6 size classes) to directly simulate change in number of trees, basal area, and cubic foot volume. Ek achieves a similar goal with fewer equations by simulating change in the number of trees by 2-inch diameter classes and then estimating basal area and volume from the known number of trees in each diameter class.

Markov models offer an alternative to stand growth simulation by differential equations (Peden *et al.* 1973, Bruner and Moser 1973). Although Markov models characterizing stand dynamics may serve many useful purposes, they generally do not provide the same opportunities for theorization that are offered by differential equation-based models.

THE ELM-ASH-COTTONWOOD MODEL

A system of differential[2] equations was sought that would simulate change in the number of trees and basal area of E-A-C stands. Ideally, such a model should be the simplest one that describes the biological phenomena (Milsum 1966) and remains consistent with the structure and function of the actual biological system (Pienaar 1965). The methods used here are similar to those of Moser (1972) that divide stand growth into the components of ingrowth, mortality, and survivor growth. Modeling stand growth by diameter classes was considered infeasible due to the small amount of data available to calibrate the model.

The following notation will be used to describe the model.

dN_i/dt = Rate at which ingrowth trees cross the 5-inch d.b.h. threshold (units: trees/acre/year).

dN_m/dt = Rate at which trees 5 inches d.b.h. or larger die (units: trees/acre/year).

N = Total number of trees 5 inches d.b.h. or larger (units: trees/acre).

dB_i/dt = Basal area represented by the ingrowth trees (units: square feet/acre/year).

dB_m/dt = Basal area represented by the mortality trees (units: square feet/acre/year).

dB_s/dt = Basal area growth on the surviving N trees (units: square feet/acre/year).

B = Total basal area of the N trees (units: square feet/acre).

The net rate of change in the number of trees per acre per year can be analyzed as the algebraic sum of the ingrowth and mortality rates (Moser 1972):

$$\frac{dN}{dt} = \frac{dN_i}{dt} - \frac{dN_m}{dt} \qquad (1)$$

The net rate of change in basal area per acre per year can be analyzed similarly. Its components are the rates of change due to ingrowth, mortality, and survivor growth:

$$\frac{dB}{dt} = \frac{dB_i}{dt} - \frac{dB_m}{dt} + \frac{dB_s}{dt} \qquad (2)$$

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[2] *Although a difference equation formulation is theoretically appropriate, we favored differential equations for analytical convenience. Numerical differences in solutions due to this choice are small.*

Table 1.—*Initial distribution of calibration data by basal area and number of trees per acre (trees 5 inches d.b.h. and larger)*

	Trees (No./acre)											
Basal area (ft²/acre)	20	40	60	80	100	120	140	160	180	200	220	240
10	2											
20		1	1									
30					1							
40			1	1		1						
50		1			1		1					
60					4	1	1	1				
70						1		2				
80				1		2	1		3			
90						2					1	
100									1			
110									1			
120												
130												1
140								1				

Equations (1) and (2) form the basis for a system of interactive differential equations that describe forest stand dynamics. To be of practical value, however, the derivatives on the right-hand sides of Equations (1) and (2) must be replaced by differential equations that are both biologically plausible and mathematically tractable. The development of these equations is presented in the following sections.

Ingrowth Rate: Number of Trees

Ingrowth occurs when trees enter the smallest measured diameter class from below. In this case a tree is classified as an ingrowth tree when it reaches 5 inches d.b.h. In real forest stands, ingrowth is a discrete phenomenon—an all or none event. However, for the stand model being developed here, ingrowth is treated as if it were a continuous process. Over the long run, the model predicts reasonable numbers of ingrowth trees.

Studies have indicated that stand density is a major factor influencing the number of seedlings and saplings in a stand. Minckler (1958) reports an increase in the number of saplings (0.6 to 4.6 inches d.b.h.) after E-A-C stand basal area was reduced by 32, 63, and 100 percent. Belanger and Pepper (1978) report a significant decrease in diameter growth of sycamore seedlings as number of trees per acre increase.

Because E-A-C stands are characteristically comprised of species that are intermediately tolerant or intolerant of competition, it is hypothesized that the rate of ingrowth can be characterized as a function of stand density. Both Ek (1974) and Moser (1972) have used negative exponential functions to express the periodic rate of ingrowth as a function of stand density. Examination of our E-A-C data showed that the annual rate of ingrowth decreased as basal area increased and that the rate of ingrowth was higher in stands with a small average diameter. These relations can be expressed as:

$$\frac{dN_I}{dt} = 10.14e^{[illegible]} \qquad (3)$$

MSE (Mean Square Error) = 14.6

e = base of natural logarithms.

The greatest annual rates of ingrowth are predicted to occur in stands with large numbers of small diameter trees. According to Equation (3), if all of the trees in a stand are less than 5 inches d.b.h., (N and B both equal 0), the ingrowth rate would be about 10 trees per acre per year. Actual forest stands containing no trees more than 5 inches d.b.h. can range from bare ground to stands with thousands of saplings per acre. Such widely different stand conditions would produce different numbers of ingrowth trees. Therefore, Equation (3) should not be used to estimate ingrowth in stands where most of the trees are less than 5 inches d.b.h.

Mortality Rate: Number of Trees

Numerous authors have attempted to predict individual tree mortality, and they have found that the mortality rate decreases as tree size increases, growth rate increases, vigor improves, or competition decreases (Monserud 1976, Hamilton and Edwards 1976, Buchman 1979). In stand simulation models, the number of mortality trees has been expressed variously in functions that predict increases in mortality with increases in number of trees and or basal area (Ek 1974, Moser 1974). Lee (1971) related mortality in even-aged stands to stand age and mean stand diameter.

The annual number of E-A-C mortality trees was positively correlated with density as measured by the number of trees and the basal area per acre. Annual mortality was expressed as separate functions of basal area and number of trees but several models combining these two independent variables into one function did not improve statistical accuracy or biological reasonableness. Consequently, the following model was judged a suitable expression for the annual number of E-A-C mortality trees per acre.

$$\frac{dN_n}{dt} = 1.106e^{0.006[illegible]} \qquad (4)$$
$$MSE = 2.7$$

Ingrowth Rate: Basal Area

The rate of basal area increase due to ingrowth is a direct function of the rate at which ingrowth trees occur. A 5-inch d.b.h. tree contributes 0.1364 square foot of basal area, so the relation between dN_i/dt and dB_i/dt is given by the differential equation:

$$\frac{dB_i}{dt} = 0.1364 \frac{dN_i}{dt} \qquad (5)$$

Because ingrowth is treated as a continuous process in the solution of this system of equations, that portion of the remeasured ingrowth trees' basal area in excess of 0.1364 square foot per tree was treated as survivor growth when the E-A-C data were analyzed.

Mortality: Basal Area

Mortality trees occur in all diameter classes, so a single large mortality tree may account for the same basal area as several smaller ones. Moser (1972) estimated the basal area of mortality trees by specifying a diameter distribution and assigning an appropriate diameter to each projected mortality tree.

Bailey and Dell (1973) used the Weibull probability density function to describe diameter distributions similar to those observed for E-A-C mortality trees. When properly calibrated, the cumulative form of the Weibull frequency distribution:

$$x = a + b[-\ln(1-F(x))]^{c^{-1}} \qquad (7)$$

where

x = the tree diameter
a = location parameter
b = scale parameter
c = shape parameter

can be used to generate diameters of mortality trees if F(x) is replaced by a uniformly distributed random variable. The maximum likelihood parameter estimates of the distribution of mortality trees by diameter class, obtained by the method of Harter and Moore (1965), were a = 5.0, b = 3.142, and c = 0.9057. A Komolgorov-Smirnov test supported the null hypothesis that the fitted Weibull distribution is equivalent to the observed distribution at the $\alpha = 0.1$ significance level. Consequently, the function

$$\frac{dB_n}{dt} = [5.0 + 3.142(-\ln(1-R))^{1.104}]^2$$
$$0.005454 \frac{dN_m}{dt} \qquad (8)$$

where
R = a uniformly distributed random variable

generates a new basal area mortality estimate for each iteration in the solution of the system of equations.

This method of determining mortality basal area cannot be expected to perform well for stands that are very different from those from which the diameter distribution of mortality trees was obtained. The mean diameter for the remeasured stands was estimated to be between 8.5 and 14.2 inches at the 0.9 probability level. For the instances in which a simulated stand has a mean diameter of less than 8.5 inches or more than 14.2 inches, the mortality trees are assumed to be of average size for that stand. This avoids predicting unreasonably large or small mortality tree diameters.

Survivor Growth: Basal Area

The amount of basal area survivor growth is expected to depend upon the size and number of the survivor trees. Moser (1972) described stand basal area survivor growth using the Chapman-Richards function with stand basal area as the independent variable. Although stand basal area was correlated with the growth rate of E-A-C survivor trees, the best results were obtained by relating the basal area survivor growth to the stand sum of diameters. The sum of diameters for the stand was approximated as the product of the number of trees in the stand and the quadratic mean stand diameter, $N\,(B/(N \cdot .005454))^{1/2}$. Linear regression through the origin was used to obtain the expression for annual basal area growth of survivor trees,

$$\frac{dB_s}{dt} = 0.03043\,(B \cdot N)^{1/2} \qquad (6)$$
$$R^2 = .82^{**}$$
$$MSE = 1.7$$

Although this function states that survivor basal area growth increases proportionately for all increases in the sum of diameters, simulated stand growth does have an upper limit. As the basal area increases, stand mortality also increases to limit basal area growth.

RESULTS AND DISCUSSION

The entire system of differential equations describing the rates of change in number of trees and basal area for elm-ash-cottonwood stands is as follows:

$$\frac{dN_i}{dt} = 10.14e^{0.002456N \; - \; 0.0[illegible]60B}$$

$$\frac{dN_m}{dt} = 1.106e^{0.006561B}$$

$$\frac{dN}{dt} = \frac{dN_i}{dt} - \frac{dN_m}{dt}$$

$$\frac{dB_i}{dt} = 0.1364 \frac{dN_i}{dt}$$

$$\frac{dB_s}{dt} = 0.03043\ (B \bullet N)^{1/2}$$

$$\frac{dB_m}{dt} = [5.0 + 3.142(-1n(1-R))^{1.104}]^2$$

$$0.005454 \frac{dN_m}{dt}$$

$$\text{if } 0.40 < \frac{B}{N} < 1.10$$

$$= \frac{B}{N} \frac{dN_m}{dt} \text{ otherwise}$$

$$\frac{dB}{dt} = \frac{dB_i}{dt} - \frac{dB_m}{dt} + \frac{dB_s}{dt}$$

The above system of equations was utilized with a fourth order Runge-Kutta algorithm (International Business Machines 1968) to develop a simulator that generates E-A-C growth and yield estimates in basal area and number of trees per acre. Inputs to the simulator are the initial values for basal area and number of trees. Outputs are the projected values for basal area and number of trees by growth components at user-specified time intervals. Tables 4 through 15 in Appendix I contain 25-year projections of total basal area, total number of trees, and cubic foot volume excluding bark for trees 5 inches d.b.h. and larger. Volume estimates were derived from the projected stand basal area using the following formula:

$$V = 8.319B^{1.211} \qquad (9)$$

where

V = cubic foot volume excluding bark for trees $\geq$ 5 inches d.b.h. and
B = basal area.

This function was fitted from the initial measured basal area and cubic foot volume in the E-A-C data. Tree volumes were estimated from the composite hardwood volume table formulae prepared by Beers (1964).

The yield tables in Appendix I are based on a single simulation trial. Because the basal area mortality function Equation (7) is stochastic, it will permit some variation in the final predictions. However, the simulation that produced the Appendix tables was performed in a manner such that from 50 to several hundred iterations were made during the solution process. A different-sized mortality tree was selected for each iteration and these small, numerous iterations made the effects of using a particular sequence of random numbers to specify mortality tree diameters almost negligible. Repeated trials with different sequences of random numbers produced results that varied by only 1 or 2 square feet of basal area after 25 years of simulation. However, it remains possible to alter the simulation program so that basal area mortality produces greater random variation in the basal area mortality during simulation trials. The FORTRAN program used for simulation is listed in Appendix II.

No data were reserved for independent validation and testing. Tests were conducted, however, to determine how well the model could predict the observed changes in stand characteristics for the 11-year remeasurement interval of the calibration data (table 2, fig. 1). Minckler's (1958) bottomland hardwood cutting study produced a small number of CFI plots suitable for independently validating the E-A-C model.[3] The study included three control plots, each approximately 2 acres in size. These plots were established in 1953 and last remeasured in 1968. The simulator was used to project the initial conditions for each of these plots to an estimate of their 1968 condition (table 3). Individual differences in the observed and predicted basal areas for the three plots after 15 years were +2, +12, and-19 ft^2 acre. The greatest error occurred on a plot within an even-aged cottonwood stand.

A desirable property of any growth simulation model is that it gives reasonable results for long projection periods. There are no data to evaluate the

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[3] *Data provided by Richard Schlesinger, North Central Forest Experiment Station, Carbondale, Illinois.*

Table 2.—*Eleven-year mean observed and mean predicted values for 35 elm-ash-cottonwood calibration plots (trees 5 inches d.b.h. and larger)*

	Trees	Basal area	Volume
	No./acre	*Ft²/acre*	*Ft³/acre*
Initial	109	62	[1]1,270
Observed	152	90	[1]2,053
Predicted	137	92	[2]2,017
Difference	-15	+2	-36
Std. error of difference	9	3.4	101

[1] Computed from the sum of observed individual tree volumes.
[2] Computed as a function of basal area, Equation (9).

accuracy of long-term E-A-C projections, but one may be encouraged if estimated stand conditions remain believable for a long projection period. Projections of two E-A-C stands for 150 years produced reasonable volume estimates (fig. 2). Although long-range projections provide an enlightening test of a model's capabilities, it is seldom prudent to rely on projections that are much longer than the interval represented by calibration data.

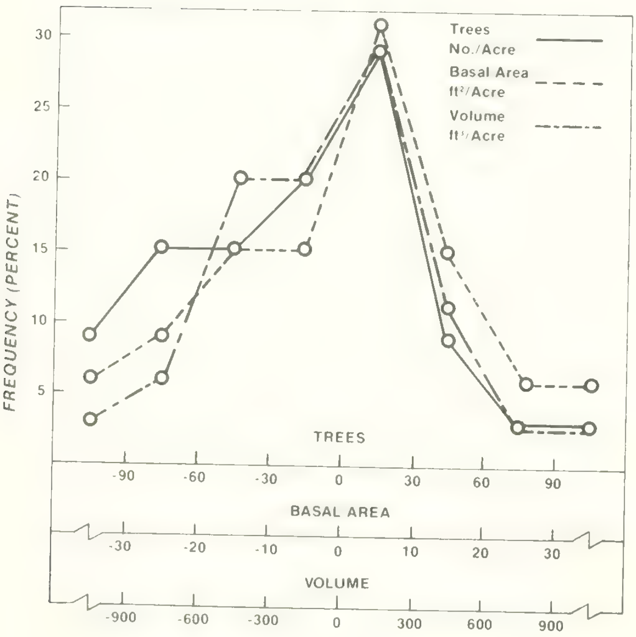

Figure 1.—*Frequency of errors in 11-year projections of 35 elm-ash-cottonwood calibration plots.*

Table 3.—*Fifteen-year mean observed and predicted values of trees 5 inches d.b.h. and larger for three elm-ash-cottonwood validation plots*

Item	Trees	Basal area	Volume
	No./acre	*ft²acre*	*ft³/acre*[1]
Initial	89	89	1,927
Final observed	83	114	2,600
Final predicted	96	113	2,533
Difference	+13	-1	-67

[1] Volumes computed as a function of basal area, Equation (9).

The growth models and simulated yield tables presented here outline some general patterns of E-A-C stand development in Indiana's bottomland. Additional research is necessary to document the effects of species composition, age structure, and management activities not addressed in this study but which certainly affect E-A-C stand growth. We hope that the information presented here will facilitate greater understanding and better utilization of the elm-ash-cottonwood forest resource.

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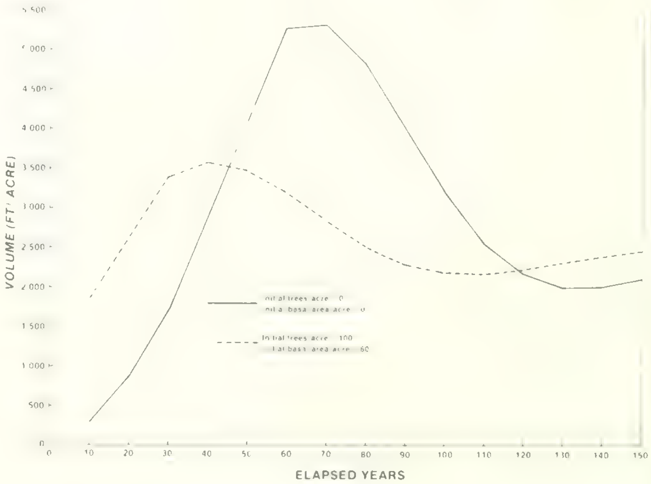

Figure 2.—*Projected volume of trees 5 inches d.b.h. and larger on two elm-ash-cottonwood plots.*

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APPENDIX I

SIMULATED ELM-ASH-COTTONWOOD YIELDS

Table 4.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 20 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
10	135	[1]59	96	128	155	175
		18	28	41	55	72
		268	471	740	1,074	1,466
20	313	52	82	109	130	147
		27	36	47	60	74
		446	637	878	1,177	1,532
30	512	47	71	93	110	123
		35	44	54	66	79
		619	810	1,044	1,329	1,658

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 5.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 40 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
10	135	[1]81	118	150	175	193
		19	31	46	62	79
		303	541	850	1,226	1,661
20	313	74	104	130	150	165
		28	39	52	66	82
		479	709	997	1,335	1,730
30	512	67	91	111	127	138
		38	48	60	73	88
		685	911	1,182	1,505	1,874
40	725	62	80	96	107	114
		48	58	68	81	94
		903	1,127	1,389	1,695	2,034
50	950	58	73	84	93	98
		56	65	75	87	99
		1,089	1,306	1,563	1,852	2,165
60	1,185	54	67	77	84	89
		61	69	79	90	98
		1,199	1,404	1,649	1,928	2,138

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 6.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 60 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
10	135	[1]103	141	172	196	212
		21	34	50	68	87
		330	602	950	1,370	1,849
20	313	95	126	151	170	182
		30	43	57	73	90
		518	787	1,118	1,507	1,948
30	512	89	113	133	148	157
		40	51	64	79	95
		716	976	1,286	1,651	2,065
40	725	83	102	117	127	133
		49	61	73	87	101
		938	1,201	1,508	1,859	2,240
50	950	78	92	102	109	112
		60	71	82	95	108
		1,717	1,442	1,738	2,061	2,421
60	1,185	73	84	91	94	95
		69	80	91	103	108
		1,415	1,674	1,960	2,267	2,412
70	1,428	70	78	83	88	91
		77	86	92	96	101
		1,592	1,827	1,985	2,107	2,225
80	1,679	68	75	81	86	89
		81	84	89	94	99
		1,713	1,787	1,909	2,047	2,164

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 7.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 80 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
20	313	[1]117	148	173	190	201
		32	46	62	79	98
		551	858	1,231	1,664	2,147
30	512	110	135	154	168	176
		41	54	69	85	103
		753	1,052	1,407	1,813	2,268
40	725	104	123	138	147	152
		51	64	78	93	109
		976	1,275	1,623	2,012	2,448
50	950	99	113	123	129	130
		61	73	87	101	116
		1,213	1,515	1,858	2,233	2,640
60	1,185	94	104	111	113	112
		71	83	96	110	124
		1,455	1,760	2,102	2,464	2,845
70	1,428	90	97	100	100	99
		81	93	105	113	117
		1,706	2,010	2,338	2,560	2,674
80	1,679	87	90	92	93	93
		91	100	104	108	112
		1,965	2,198	2,316	2,426	2,523
90	1,937	85	88	91	92	93
		94	98	102	107	110
		2,041	2,153	2,267	2,376	2,475
100	2,200	82	84	85	85	85
		102	104	106	108	110
		2,257	2,316	2,374	2,426	2,472

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[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft acre), and the third is simulated volume yield (cu ft/acre).

Table 8.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 100 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
20	313	[1]138	171	195	212	221
		33	49	66	85	106
		580	923	1,338	1,816	2,350
30	512	131	157	176	188	194
		43	58	74	92	111
		790	1,130	1,527	1,982	2,485
40	725	125	145	159	168	171
		52	66	82	99	116
		1,003	1,337	1,726	2,166	2,643
50	950	120	135	144	149	150
		63	76	91	107	123
		1,246	1,586	1,967	2,385	2,833
60	1,185	115	126	132	134	132
		72	86	100	115	131
		1,489	1,830	2,208	2,615	3,048
70	1,428	111	118	120	119	115
		83	96	110	125	133
		1,745	2,093	2,473	2,870	3,116
80	1,679	107	111	111	108	104
		93	106	120	126	129
		2,007	2,355	2,735	2,905	3,005
90	1,937	104	105	103	101	97
		103	115	120	124	126
		2,275	2,618	2,747	2,846	2,910
100	2,200	101	100	99	96	93
		112	117	120	123	124
		2,523	2,649	2,748	2,819	2,859
110	2,469	100	98	96	93	90
		115	118	121	123	124
		2,597	2,701	2,778	2,826	2,846
120	2,744	97	94	91	87	84
		123	125	125	125	124
		2,824	2,873	2,890	2,878	2,842

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[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft acre), and the third is simulated volume yield (cu ft/acre).

Table 9.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 120 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
20	313	[1]160 35 607	193 52 985	218 71 1,442	233 91 1,968	241 113 2,550
30	512	153 44 822	179 61 1,202	197 79 1,644	209 98 2,140	213 118 2,690
40	725	146 54 1,044	167 70 1,422	180 87 1,850	188 105 2,328	190 124 2,863
50	950	141 64 1,277	156 79 1,653	166 95 2,076	170 113 2,539	169 131 3,045
60	1,185	136 74 1,523	147 89 1,900	153 105 2,323	154 121 2,780	151 138 3,263
70	1,428	132 84 1,782	139 99 2,169	141 115 2,599	139 131 3,049	134 147 3,505
80	1,679	128 94 2,046	132 109 2,436	131 124 2,863	127 140 3,298	120 145 3,440
90	1,937	125 104 2,317	125 119 2,711	122 134 3,134	117 139 3,282	110 142 3,366
100	2,200	122 114 2,592	120 129 2,987	115 135 3,172	109 139 3,267	103 140 3,306
110	2,469	119 125 2,872	115 133 3,108	110 137 3,214	104 139 3,267	97 139 3,267
120	2,744	117 132 3,072	112 136 3,194	106 138 3,264	99 139 3,280	93 138 3,246
130	3,023	115 136 3,195	109 139 3,286	103 140 3,321	96 140 3,303	90 138 3,238
140	3,307	113 144 3,408	106 145 3,446	99 144 3,424	91 141 3,350	85 137 3,232

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[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 10.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 140 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
30	512	[1]174 46 852	201 64 1,270	219 83 1,757	230 104 2,301	233 126 2,898
40	725	168 56 1,079	188 73 1,496	202 91 1,965	209 111 2,486	209 132 3,066
50	950	162 65 1,312	178 82 1,723	187 100 2,190	190 119 2,710	188 139 3,268
60	1,185	157 75 1,555	168 91 1,971	174 109 2,443	174 127 2,949	170 146 3,481
70	1,428	152 85 1,816	160 102 2,244	162 119 2,719	159 137 3,219	153 155 3,729
80	1,679	149 96 2,082	152 112 2,529	151 129 2,997	146 146 3,488	138 158 3,842
90	1,937	145 106 2,356	146 122 2,795	142 139 3,268	135 152 3,667	126 157 3,795
100	2,200	142 116 2,633	140 132 3,075	134 148 3,536	126 153 3,681	117 155 3,749
110	2,469	139 126 2,915	135 142 3,363	127 150 3,603	119 153 3,694	110 154 3,710
120	2,744	137 136 3,202	130 148 3,547	122 152 3,666	113 154 3,710	104 153 3,680
130	3,023	135 146 3,488	127 152 3,660	118 155 3,735	108 155 3,734	99 152 3,661
140	3,307	133 152 3,653	124 156 3,756	114 157 3,802	104 156 3,759	95 152 3,648

---

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 11.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 160 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
30	512	[1]196 47 881	224 66 1,336	242 87 1,866	251 110 2,459	253 133 3,099
40	725	189 57 1,112	210 76 1,369	223 96 2,084	229 117 2,652	229 139 3,282
50	950	183 67 1,348	199 85 1,803	208 104 2,310	211 125 2,874	207 146 3,480
60	1,185	178 76 1,590	189 94 2,046	195 113 2,560	194 133 3,119	189 154 3,708
70	1,428	173 87 1,849	181 104 2,314	183 123 2,835	179 143 3,384	172 162 3,945
80	1,679	169 97 2,117	173 115 2,604	172 133 3,120	166 152 3,661	156 171 4,207
90	1,937	166 107 2,393	167 125 2,872	163 143 3,388	155 161 3,918	144 170 4,196
100	2,200	163 117 2,672	161 135 3,159	154 153 3,674	144 166 4,063	133 170 4,174
110	2,469	160 128 2,956	155 145 3,454	147 162 3,954	136 167 4,099	124 169 4,146
120	2,744	157 137 3,235	150 155 3,745	140 165 4,043	129 168 4,131	117 168 4,122
130	3,023	155 148 3,533	146 163 3,991	135 168 4,124	123 169 4,158	111 167 4,098
140	3,307	153 158 3,826	142 168 4,116	130 171 4,201	118 170 4,186	106 166 4,080

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft acre), and the third is simulated volume yield (cu ft/acre).

Table 12.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 180 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
40	725	[1]211 58 1,143	232 78 1,639	245 100 2,198	250 122 2,811	249 146 3,480
50	950	204 68 1,383	221 88 1,881	229 108 2,426	231 130 3,034	227 153 3,686
60	1,185	199 78 1,629	211 97 2,125	216 118 2,675	214 139 3,286	208 161 3,916
70	1,428	194 88 1,885	202 107 2,384	204 127 2,947	200 148 3,543	191 169 4,162
80	1,679	190 98 2,151	194 117 2,672	193 138 3,239	186 158 3,830	175 178 4,428
90	1,937	186 108 2,428	187 127 2,949	183 147 3,511	174 167 4,099	162 183 4,577
100	2,200	183 119 2,10	181 138 3,239	174 157 3,805	164 176 4,372	150 183 4,573
110	2,469	180 129 2,995	176 148 3,538	167 167 4,099	154 180 4,470	140 183 4,561
120	2,744	178 139 3,275	171 158 3,833	160 177 4,382	146 181 4,525	132 182 4,532
130	3,023	175 149 3,576	166 169 4,142	153 180 4,485	139 183 4,567	125 182 4,550
140	3,307	173 159 3,871	162 178 4,429	148 183 4,575	133 184 4,601	119 181 4,513

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft acre), and the third is simulated volume yield (cu ft acre).

Table 13.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 200 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
50	950	[1]226	242	251	252	246
		69	91	113	136	160
		1,416	1,955	2,552	3,193	3,899
60	1,185	220	232	237	235	227
		79	100	122	145	168
		1,665	2,207	2,795	3,448	4,135
70	1,428	215	223	224	220	210
		89	110	131	154	176
		1,921	2,462	3,062	3,709	4,375
80	1,679	211	215	213	206	195
		99	120	141	163	184
		2,183	2,735	3,333	3,973	4,612
90	1,937	207	208	203	194	180
		110	130	152	173	194
		2,462	3,026	3,640	4,279	4,901
100	2,200	204	202	195	183	168
		120	140	161	182	195
		2,745	3,316	3,929	4,548	4,956
110	2,469	201	196	187	173	157
		130	151	171	191	196
		3,033	3,619	4,228	4,825	4,963
120	2,744	198	191	179	164	148
		140	161	182	194	196
		3,318	3,917	4,532	4,896	4,963
130	3,023	195	186	172	156	140
		151	172	191	196	195
		3,617	4,231	4,824	4,958	4,956
140	3,307	193	182	166	150	133
		161	182	195	197	195
		3,913	4,530	4,928	5,002	4,939

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 14.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 220 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
60	1,185	[1]241	253	258	255	246
		81	103	126	150	175
		1,700	2,283	2,920	3,604	4,340
70	1,428	236	244	245	240	229
		91	113	135	159	183
		1,957	2,543	3,177	3,868	4,581
80	1,679	232	236	234	226	213
		101	123	145	169	192
		2,225	2,819	3,462	4,148	4,840
90	1,937	228	229	224	214	199
		111	133	155	178	200
		2,495	3,098	3,751	4,423	5,107
100	2,200	224	222	215	203	186
		121	143	166	188	208
		2,780	3,392	4,051	4,31	5,341
110	2,469	221	216	207	192	174
		132	153	176	198	208
		3,069	3,697	4,356	5,023	5,355
120	2,744	218	211	199	183	164
		142	164	186	205	209
		3,356	4,002	4,671	5,262	5,369
130	3,023	216	206	192	174	156
		152	174	196	208	209
		3,656	4,316	4,980	5,330	5,365
140	3,307	213	202	186	167	148
		162	184	205	209	208
		3,954	4,618	5,262	5,387	5,355

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre).

Table 15.—*Simulated elm-ash-cottonwood stand yield from an initial condition of 240 trees per acre*

Initial basal area	Initial volume	Elapsed years from initial conditions				
		5	10	15	20	25
60	1,185	[1]262 82 1,733	275 106 2,357	279 130 3,033	276 156 3,68	266 182 4,551
70	1,428	257 92 1,993	265 115 2,620	266 140 3,295	260 165 4,032	248 190 4,791
80	1,679	253 102 2,259	257 125 2,889	255 149 3,571	246 174 4,304	233 199 5,055
90	1,937	248 112 2,528	250 135 3,176	245 160 3,873	234 184 4,612	218 208 5,344
100	2,200	245 122 2,813	243 146 3,468	235 170 4,175	222 194 4,900	205 217 5,614
110	2,469	242 133 3,104	237 156 3,773	227 180 4,478	212 203 5,197	192 221 5,735
120	2,744	239 143 3,392	232 167 4,081	219 190 4,797	202 213 5,510	181 221 5,756
130	3,023	236 153 3,693	227 177 4,393	212 201 5,110	193 219 5,690	172 221 5,765
140	3,307	234 163 3,989	222 187 4,701	205 210 5,414	185 221 5,757	164 221 5,760

[1] The first number of each trio is the simulated yield in number of trees per acre, the second is the simulated yield in basal area (sq ft/acre), and the third is simulated volume yield (cu ft/acre)

APPENDIX II

FORTRAN PROGRAM FOR ELM-ASH-COTTONWOOD YIELD SIMULATION

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C*********************************************************************
C  THIS IS A SIMPLE PROGRAM THAT INTEGRATES THE SYSTEM OF
C  ELM-ASH-COTTONWOOD DIFFERENTIAL EQUATIONS DESCRIBING
C  CHANGE IN NUMBER OF TREES AND BASAL AREA PER ACRE.
C  THIS PROGRAM CALLS THE IBM SCIENTIFIC SUBROUTINE RKGS
C  WHICH DOES THE ACTUAL NUMERICAL INTEGRATION.  FOR MORE
C  INFORMATION ON RKGS REFER TO :
C      INTERNATIONAL BUSINESS MACHINES CORPORATION. 1968.
C      SYSTEM/360 SCIENTIFIC SUBROUTINE PACKAGE
C      (360-CM-03X) VERSION III PROGRAMMER'S MANUAL.
C      4TH ED. TECHNICAL PUBLICATIONS DEPARTMENT, WHITE PLAINS,
C      NEW YORK.  452 P.
C  INPUTS REQUIRED ARE INITIAL NUMBER OF TREES PER ACRE,
C  INITIAL BASAL AREA PER ACRE, LENGTH OF DESIRED PROJECTION,
C  AND FREQUENCY OF PRINTED OUTPUT.  ALL VALUES ARE FOR TREES
C  5 INCHES DBH AND LARGER.
C*********************************************************************
      EXTERNAL FCT,OUTP,RKGS
      DIMENSION PRMT(5),Y(7),DERY(7),AUX(8,7)
      COMMON TNT1,BAT1,TIMER,PERIOD,REPORT
      TIMER = 0.0

C*********************************************************************
C  READ IN INITIAL NUMBER OF TREES, INITIAL BASAL AREA,
C  PROJECTION PERIOD, AND REPORTING INTERVAL.
C      TNT1 = NUMBER OF TREES PER ACRE 5 INCHES DBH OR LARGER
C      BAT1 = BASAL AREA OF THE TNT1 TREES
C      PERIOD = DESIRED PROJECTION LENGTH IN YEARS
C      REPORT = YEARS BETWEEN REPORTED OUTPUT
C*********************************************************************
      READ(5,500)TNT1,BAT1,PERIOD,REPORT
  500 FORMAT(2F4.0,2F3.0)

C*********************************************************************
C  INITIALIZE ARRAY PRMT (USED BY RKGS)
C      PRMT(1) = LOWER BOUND OF INTEGRATION
C      PRMT(2) = UPPER BOUND OF INTEGRATION
C      PRMT(3) = INITIAL STEP SIZE
C      PRMT(4) = ERROR TOLERANCE
C*********************************************************************
      PRMT(1) = 0.0
      PRMT(2) = PERIOD + .1
      PRMT(3) = 0.1
      PRMT(4) = 0.001
```

```
C***********************************************************************
C  INITIALIZE ARRAY Y WITH THE INITIAL CONDITIONS FOR EACH
C  OF THE DIFFERENTIAL EQUATIONS IN THE SIMULATOR.
C      Y(1) = CUMULATIVE NUMBER OF INGROWTH TREES PER ACRE
C      Y(2) = CUMULATIVE NUMBER OF MORTALITY TREES PER ACRE
C      Y(3) = NUMBER OF TREES PER ACRE.
C      Y(4) = CUMULATIVE BASAL AREA INGROWTH PER ACRE
C      Y(5) = CUMULATIVE BASAL AREA SURVIVOR GROWTH PER ACRE
C      Y(6) = CUMULATIVE BASAL AREA MORTALITY PER ACRE
C      Y(7) = BASAL AREA PER ACRE
C  VALUES MUST BE GREATER THAN ZERO.
C***********************************************************************
      Y(1) = 0.00001
      Y(2) = 0.00001
      Y(3) = TNT1
      Y(4) = 0.00001
      Y(5) = 0.00001
      Y(6) = 0.00001
      Y(7) = BAT1

C***********************************************************************
C  INITIALIZE THE ARRAY NDIM TO THE TOTAL NUMBER OF EQUATIONS
C***********************************************************************
      NDIM=7

C***********************************************************************
C  INITIALIZE THE ARRAY OF EQUATION WEIGHTS, DERY.
C***********************************************************************
      DO 10 I=1,NDIM
      DERY(I)=1.0/FLOAT(NDIM)
   10 CONTINUE


C***********************************************************************
C  WRITE OUTPUT TABLE HEADING.  CFV IS CUBIC FOOT VOLUME
C  ESTIMATED AS A FUNCTION OF BASAL AREA.
C***********************************************************************
      CFV=8.319*Y(7)**1.2112
      WRITE(6,600)TNT1,BAT1,CFV
  600 FORMAT(1H1,17X,34HSIMULATED ELM-ASH-COTTONWOOD YIELD,/
     +10X,51H(PER ACRE VALUES FOR TREES 5 IN. D.B.H. AND LARGER),/19X,
     +31H(TREES 5 INCHES DBH AND LARGER)//19X,
     +23HINITIAL NUMBER OF TREES,
     +F6.0/19X,27HINITIAL BASAL AREA (FT.SQ.),F6.0/
     +19X,25HINITIAL CUBIC FOOT VOLUME,F6.0///
     +60H        ELAPSED         NUMBER          BASAL      CUBIC FOOT/
     +60H           TIME       OF TREES           AREA          VOLUME/)

C***********************************************************************
C  CALL THE RKGS SUBROUTINE TO INTEGRATE THE SYSTEM OF
C  DIFFERENTIAL EQUATIONS.
C***********************************************************************
      CALL RKGS(PRMT,Y,DERY,NDIM,IHLF,FCT,OUTP,AUX)
      STOP
      END
      SUBROUTINE FCT(X,Y,DERY)
      DIMENSION Y(7),DERY(7)
      COMMON INT1,SAT1,TIMER,PERIOD,REPORT
C*************************************************************************
C  THIS SUBROUTINE HOLDS THE RIGHT HAND SIDES OF THE
C  DIFFERENTIAL EQUATIONS TO BE SOLVED SIMULTANEOUSLY.
C  DERY(1) IS THE DERIVATIVE OF Y(1), DERY(2) IS THE
C  DERIVATIVE OF Y(2), ETC.
C*************************************************************************
      DERY(1) = 10.189 * EXP(0.0024561 * Y(3) - 0.015502 * Y(7))

      DERY(2) = 1.1961 * EXP(0.0066612 * Y(7))

      DERY(3) = DERY(1) - DERY(2)

      DERY(4) = 0.13635 * DERY(1)

      DERY(5) = 0.330429 * SQRT(Y(7) * Y(3))

      DERY(6) = (((3.1424*((-ALOG(1.0-RANF(0)))**1.1041)) - 5.0)
     2**2)*0.005454*DERY(2)
      QUAD = Y(7)/Y(3)
      IF(QUAD.GT.1.1.OR.QUAD.LT.0.45) DERY(6) = QUAD*DERY(2)

      DERY(7) = DERY(4) - DERY(5) - DERY(6)

      RETURN
      END



      SUBROUTINE OUTP(X,Y,DERY,IHLF,NDIM,PRMT)
      DIMENSION Y(NDIM),DERY(NDIM),PRMT(5)
      COMMON INT1,SAT1,TIMER,PERIOD,REPORT

C*************************************************************************
C  SUBROUTINE OUTP PRINTS SELECTED OUTPUT FROM THE SOLUTION
C  PROCESS.  THIS SUBROUTINE IS CALLED AT LEAST ONCE EVERY
C  PRMT(5) YEARS.  AT EACH CALL TO OUTPUT THE VALUES OF
C  ARRAY Y (THE CURRENT CUMULATIVE YIELD VALUES) AND X
C  (THE TIME VARIABLE) ARE PASSED TO SUBROUTINE OUTP.  THESE
C  VALUES ARE PRINTED EVERY "REPORT" YEARS.
C*************************************************************************
      ELAPSED=X-TIMER
      IF(ELAPSED.GE.(REPORT-.001))GO TO 5
      GO TO 10

    5 CFV=8.319*Y(7)**1.2112
      WRITE(6,6000)X,Y(3),Y(7),CFV
 6000 FORMAT(4(5X,F10.0))
     +,Y(3)
      TIMER = TIMER + REPORT

   10 RETURN
      END
```

Shifley, Stephen R.; Moser, John W., Jr.; Brown, Kenneth M.
Growth and yield model for the elm-ash-cottonwood type in Indiana. Res. Pap. NC-218. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1982. 16 p.

Presents a growth and yield model for the elm-ash-cottonwood forest type in Indiana and discusses model validity. Gives simulated yield estimates for a wide range of stand conditions.

KEY WORDS: Bottomland hardwoods, yield tables, simulation.

United States Department of Agriculture

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North Central Forest Experiment Station

Research Paper **NC-219**

Tall Shrub Layer Biomass in Conifer Plantations of Northeastern Minnesota

Lewis F. Ohmann

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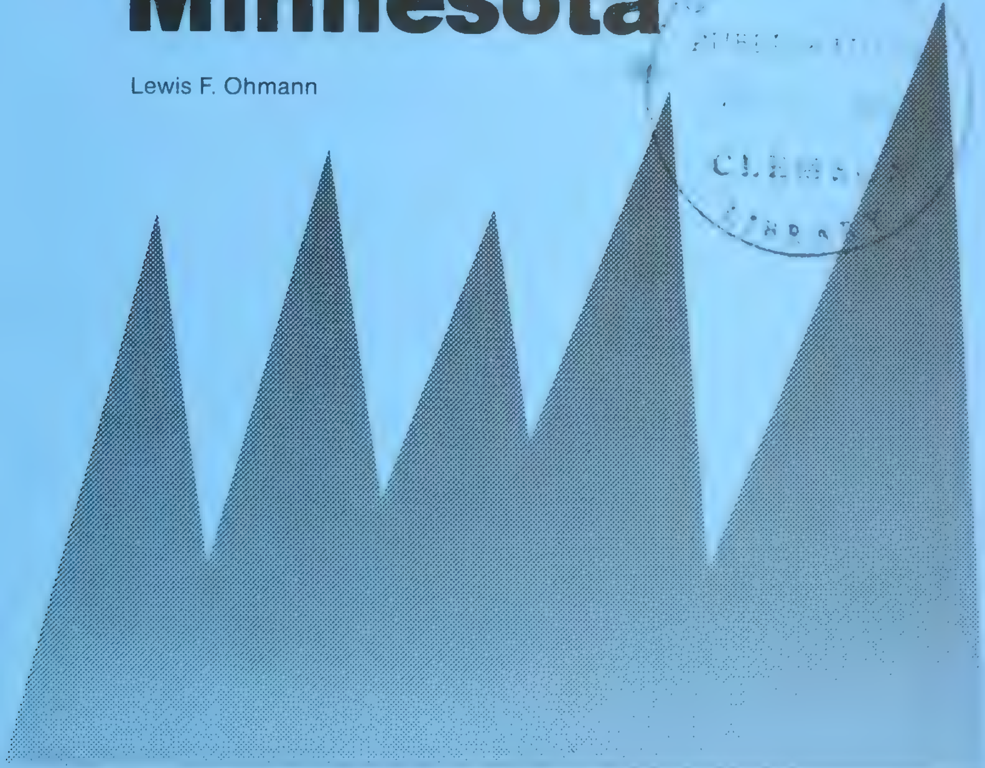

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely
FOLLOW THE LABEL
U.S. DEPARTMENT OF AGRICULTURE

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Appendix 15

TALL SHRUB LAYER BIOMASS IN CONIFER PLANTATIONS OF NORTHEASTERN MINNESOTA

Lewis F. Ohmann
Principal Plant Ecologist

Management for wildlife habitat on public land occurs primarily through manipulation of forest stands for timber management. Common examples of stand manipulation are: regeneration of new stands via harvesting followed by natural reproduction, seeding, or planting; release of regenerated stands from competing vegetation; and later thinning or other stand improvement treatments. Because good timber management is not necessarily good wildlife habitat management (Thomas *et al.* 1976), land managers should know the impacts that silvicultural practices might have on wildlife habitat. This kind of information can help meet legislative and policy requirements that land managed by the USDA Forest Service support an abundance and diversity of wildlife.

Large-scale planting programs in the Lake States began with the Civilian Conservation Corps in 1933 (Krefting 1975). By 1966 more than 1 million acres (404,700 ha) of conifers had been planted in Michigan (Gysel 1966). The Superior National Forest of northeastern Minnesota has established about 300,000 acres (121,410 ha) of conifer plantations. Conifer plantations make up about 10 percent of the Forest's Isabella and Halfway (now part of the Kawishiwi) Ranger Districts, where this study was conducted (Peek *et al.* 1976).

The acreage of conifer plantation in northeastern Minnesota will probably increase in response to more intensive forest management mandated by recent Federal legislation that restricts timber harvest in the Boundary Waters Canoe Area Wilderness.

The principal vertebrate wildlife using these plantations for browse (food) are moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), and snowshoe hare (*Lepus americanus*) (Grigal and Moody 1980, Mooty 1976, Peek *et al.* 1976).

This paper describes the impacts of some common silvicultural practices on biomass production by tall shrubs and small broadleaf trees in conifer plantations successfully established between 1945 and 1974 near Isabella, Minnesota. Portions of this biomass—the leaf and current annual woody twig growth—serve as potential browse for wildlife.

METHODS

Study plantations on relatively uniform soils (coarse loamy Dystric Eutrochrepts)[1] were selected from within a 33-mi^2 (85.5 km^2) area near Isabella, Minnesota (lat. 47° 35'N, long. 91° 20'W). Parts of the area had been logged for red pine (*Pinus resinosa* Ait.) and white pine (*Pinus strobus* L.) during northern Minnesota's early logging period (ca. 1900-1920). However, the sample was selected from plantations established following the clearcut of natural stands of pine (jack pine, *Pinus banksiana* Lamb.) or mixed pine and spruce (usually black spruce, *Picea mariana* (Mill.) B.S.P.) during the mid-1940's through the 1970's.

Sample selection was designed to represent a spectrum of plantation ages and the silvicultural techniques practiced in the study area over the 30-year period. These conditions were represented on a cover-type map with overlays (Hagen and Meyer 1977) that depicted plantation establishment dates, tree species planted, and site preparation and plantation release methods. Based on the overlays, plantations

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[1] *Personal communication with D. F. Grigal.*

were arbitrarily classed by 5-year segments from earliest available (1945-1949) to most recent (1970-1974). The plantations were also categorized on the basis of two silvicultural practices: (1) site preparation for planting; and (2) release from competing vegetation; and on the species of trees planted.

Site preparation methods included: (1) no record of a site preparation treatment applied; (2) mechanical disking of the ground surface, probably by an Athens-type disk plow (Rudolf 1950); (3) dozer-blade shearing of woody stems and scraping of at least some of the forest floor material and depositing it in specific areas, generally windrows (rock-raking) (Noble *et al.* 1977); and (4) chemical herbicide (usually either 2,4-D, or a mixture of 2,4-D and 2,4,5-T) to the post-logging vegetation. Plantation release methods included: (1) chemical (in more recent years usually 2,4-D herbicide applied by helicopter (Hagen and Meyer 1977), but earlier could have included a mixture of 2,4-D and 2,4,5-T applied less effectively from fixed-wing aircraft); (2) manual (hand removal of competing vegetation one or more times); (3) manual plus chemical (a combination of both types of release, usually a manual release followed by a chemical release several years later); and (4) unknown (no record of release). Tree species planted were categorized as: (1) pine (either red pine, jack pine, or a combination of both); (2) pine and spruce (white spruce, *Picea glauca* (Moench) Voss); or (3) spruce.

The plantations were randomly chosen on the cover-type map and overlays by use of random numbers selected from right angle baselines drawn on the map. Samples were drawn until at least 3 sites were picked representing all categories of species planted, site preparation, and plantation release practiced within each of the 5-year establishment periods. Because silvicultural technology changed, not all of the listed practices were represented in each establishment period. For example, disking for site preparation was not applied in plantations established after 1964, chemical site preparation was not practiced before 1965, no plantations were established without site preparation later than 1965, and rock-raking was not used until 1960.

Diameters of shrubs and deciduous tree species under 1 inch (2.5 cm) diameter at breast height (d.b.h.) were measured to the nearest one-tenth of an inch (0.25 cm) at a point 6 inches (15 cm) above ground level in circular mil-acre (4.05 m^2) plots. Shrub diameters were tallied by species in 10 plots distributed systematically throughout a homogeneous portion of each plantation. For efficiency, stems were tallied in only one-half of each mil-acre plot in plantations where shrubs were especially abundant.

Diameters were used to estimate ovendry weight of the leaves, current annual woody twigs, and total aboveground stem wood through use of allometric estimation equations previously developed for trees and shrubs of this area (Grigal and Ohmann 1977, Ohmann *et al.* 1976).

Biomass estimates for leaf (LEAF), current annual wood twig (TWIG), and total aboveground stem wood (WOOD) were summarized by plantation establishment period (YEAR), method of plantation release (RELEASE), method of site preparation (PREP), and tree species planted (SPECIES).

Total plantation shrub layer biomass and biomass of species that were represented in at least 15 of the 28 treatment categories were, after logarithmic transformation, analyzed for difference among treatments and treatment combinations through three-way analyses of variance (ANOVAs).

The effect of treatment categories was also assessed through Multiple Classification Analysis (MCA). MCA is a multivariate technique for examining the simultaneous interrelations between several treatments and a dependent variable (Andrews *et al.* 1973). It is especially useful when the treatments are correlated to some degree and where the attributes examined are not experimentally manipulated (Nie *et al.* 1975), as in this study. A unique feature of MCA is the ability to show the effect of each treatment category on the dependent variable (biomass) both before and after taking into account the effects of the other treatment(s) being considered. The classification computes a grand mean for the dependent variable (biomass) and for category means of each treatment, expressed as deviations from the grand mean. These deviations indicate the effect of each treatment category. The analysis also provides values for each treatment category, expressed as deviations from the grand mean after adjustment for other treatments. These adjusted values indicate the "true" effects of the treatment category on the dependent variable—the effects remaining after variation due to other treatments has been accounted for.

RESULTS AND DISCUSSION

The sample consisted of nine or more plantations for each of the establishment periods except for 1970-1974 when not enough plantations were available for sampling (table 1). Some of the PREP, RELEASE, and SPECIES categories also had limited representation and only a minimum 3 samples were selected from each of them because of their scarcity in the plantation population (table 1).

Two of the independent variables, YEAR and PREP, were significantly positively correlated. This probably reflects changes in site preparation practices. YEAR and SPECIES, as well as PREP and SPECIES were also slightly positively related. YEAR and RELEASE, PREP and RELEASE, and SPECIES and RELEASE were weakly negatively related:

Independent Variable	Pearson's R	Probability
YEAR-PREP	0.7134	0.000
YEAR-RELEASE	-0.1100	.216
YEAR-SPECIES	.2022	.073
PREP-RELEASE	-0.0691	.312
PREP-SPECIES	.1378	.162
RELEASE-SPECIES	-0.1569	.131

It is important to recognize the degree of correlation because positively related treatments, when considered together, will explain less of the variation than the sum of them considered separately. On the other hand, negatively related treatments that are positively related to the dependent variable will, when considered together, explain more of the variation in the dependent variable than the sum of them considered separately. The independent variables YEAR and PREP are correlated sufficiently so that when considered together in a three-way ANOVA or MCA the amount of variation explained is less than actually present.

None of the 28 woody species was found in the sample plots within every plantation, and only 7 species were tallied in more than half (27) of the plantations (table 2). However, these seven (the tall shrubs *Corylus, Amelanchier, Alnus, Prunus,* and *Salix;* and the trees under 1 inch d.b.h., *Acer* and *Populus)* accounted for more than 80 percent of the total estimated LEAF, TWIG, and WOOD biomass. Although not as dominant, the smaller shrubs can provide browse, especially because they tend to produce a higher proportion of their biomass as leaves and twigs. For example, for the tall shrub and tree species there was a generally consistent ratio of LEAF to WOOD biomass of about 0.14, and TWIG to WOOD biomass ratio of about 0.04. Many of the smaller shrubs, however, had higher LEAF and TWIG TO WOOD biomass ratios; for example, *Rubus strigosus* 0.66 and 0.17, *Rubus parviflorus* 0.79 and 1.0, *Rosa acicularis* 0.38 and 0.16, *Rosa blanda* 0.29 and 0.17, and most of the *Lonicera* species (*L. oblongifolia* 0.33 and 0.21, *L. hirsuta* 0.22 and 0.08, and *L. dioica* 0.40 and 0.15). Not only do these species have browse potential but some, *Rosa* and *Lonicera* for example, are highly preferred snowshoe hare and white-tailed deer foods during some seasons (Grigal and Moody 1982[2]).

In addition to total plantation biomass, 15 species were represented by sufficient biomass in the various categories to test for differences among treatments through ANOVA. Three-way ANOVAs were conducted to examine the combined effects of the silvicultural practices on the estimated LEAF, TWIG, and WOOD biomass values in addition to individual treatment effects. Some ANOVAs could not be conducted because the close relation between chemical site preparation and spruce species planted (PREP and SPECIES) resulted in a singular matrix. Of the 96 3-way ANOVAs conducted, 38 LEAF, TWIG, or WOOD cases were significant at the $p = \geqslant 0.10$ level for one or more sources of variation (see Appendix).

While ANOVA indicates the presence of differences among treatment categories, it does not indicate which treatment categories differ from the oth-

Table 1.--Independent variable categories against which the biomass estimates of the tall shrub layer (LEAF), current annual woody twig growth (TWIG), and total aboveground wood (WOOD) were tested from 53 conifer plantations near Isabella, Minnesota

Establishment period		Site preparation		Plantation release		Species planted	
YEAR	Plantations	PREP	Plantations	RELEASE	Plantations	SPECIES	Plantations
	Number		Number		Number		Number
1945-1949	9	None	11	Chemical	17	Pine	38
1950-1954	9	Disk	21	Manual	21	Pine and Spruce	12
1955-1959	9	Rock-rake	18	Manual plus chemical	3	Spruce	3
1960-1964	13	Chemical	3	No record	12		
1965-1969	9						
1970-1974	4						

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[2] *Personal communication with Lynn Rogers.*

Table 2.--Mean and standard error estimates for leaf, current annual woody twig, and total aboveground woody stem biomass (ovendry) of shrub layer species in conifer plantations near Isabella, Minnesota

Species	Plantations	LEAF		TWIG		WOOD	
		$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
	Number	Pounds/acre					
Total (stand totals all shrub layer species)	53	285.6	26.5	75.9	7.4	2,059.4	212.7
Rubus strigosus	51	20.2	4.0	5.1	.8	30.6	6.2
Corylus cornuta	50	110.4	15.0	26.0	3.3	841.7	110.1
Rosa acicularis	48	6.2	.9	2.7	.4	16.4	2.5
Amelanchier spp.	43	20.6	3.1	5.7	.8	166.8	31.4
Alnus crispa	34	109.7	20.1	33.2	6.1	935.1	172.7
Populus tremuloides	34	43.0	12.9	5.2	1.4	252.6	72.0
Prunus pensylvanica	31	9.3	2.0	2.4	.5	83.6	17.3
Lonicera canadensis	26	2.3	.4	.8	.1	13.6	2.5
Salix spp.	24	26.1	8.6	3.2	1.0	233.4	87.6
Betula papyrifera	19	2.0	.6	.8	.4	18.2	8.2
Lonicera oblongifolia	18	.8	.4	.5	.3	2.5	1.3
Acer spicatum	15	21.0	5.4	12.1	3.3	240.3	58.1
Prunus virginiana	15	12.4	2.5	2.7	.7	65.9	17.0
Cornus rugosa	13	21.4	9.7	4.5	2.0	85.6	42.9
Lonicera hirsuta	12	1.7	.4	.7	.2	7.8	3.7
Acer rubrum	8	26.8	15.9	21.7	9.8	200.9	118.7
Rosa blanda	6	2.4	.8	1.4	.5	8.2	3.4
Ribes spp.	4	1.3	1.2	.6	.5	11.7	11.3
Sorbus americana	3	2.5	1.5	.9	.6	19.4	13.6
Lonicera villosa	3	2.1	1.3	.4	.2	9.0	4.1
Lonicera dioica	2	.8	0	.3	0	1.9	0
Populus balsamea	2	2.8	2.8	.6	.6	25.2	24.1
Alnus rugosa	1	31.4	—	29.7	—	311.8	—
Cornus stolonifera	1	23.2	—	3.5	—	124.9	—
Rhamnus alnifolia	1	15.1	—	3.3	—	86.9	—
Ribes hirsuta	1	.1	—	.1	—	.4	—
Rubus parviflorus	1	55.3	—	70.2	—	70.2	—
Viburnum rafinesquianum	1	8.3	—	.9	—	32.3	—

ers. Means that were detected by the Student-Newman-Keuls test as significantly different (p = ≥0.05) included 10 categories of YEAR, four each of PREP and SPECIES, and two of RELEASE (see Appendix).

The relation of biomass to each treatment category is difficult to interpret because of the complex relation of treatments and categories and their influence on the resulting biomass values. The ANOVA and MCA analyses help to clarify these relations by making it possible to examine the influence of a treatment and its categories after adjustment for the effect of the other treatments. Below, I present summary interpretations of these analyses. However, because the interpretations are based on adjusted values, the summary does not in all cases conform to the influence levels depicted in Appendix figure 1.

Ecological landtypes for the Superior National Forest have recently been described although they have not been extensively mapped. The most probable ELTs for the plantations in this study are: ELT-11 (UDHD) Upland Deep Loamy over Sandy Dry, ELT-13 (UDLDC) Upland Deep Loamy Dry Coarse, and ELT-14 (UDLDM) Upland Deep Medium Loamy Dry. These ELTs are estimated to occupy 10, 8, and 11 percent of the land area within the Superior National Forest, respectively. The results presented here would be most applicable to conifer plantations located on these ELTs.

Plantation Total

The treatment PREP explains a statistically significant amount of the variation in LEAF and WOOD plantation biomass. Because total biomass is comprised of a combination of species for which greater or lesser biomass for any one species in any treatment category may balance out, it is not surprising that the variation accounted for by a treatment may be statistically significant, but not very high. For LEAF and WOOD, the treatment PREP is most important, explaining 15 and 18 percent of the biomass variation, respectively. The other statistically nonsignificant variation trends for LEAF and WOOD are SPECIES (12 and 14 percent), RELEASE (7 and

11 percent), and YEAR (2 and 5 percent). For TWIG the ranking is PREP 14 percent, RELEASE 10 percent, SPECIES 9 percent, and YEAR 2 percent.

The most important treatment categories associated with above-average total plantation biomass values were older plantations that had been prepared by disking, planted to pine, and later released from competing vegetation by manual methods. Categories associated with below-average biomass values were sites that had been prepared by chemical methods for planting to spruce and later released by chemical methods.

There were no statistical differences in total shrub stratum biomass between 5-year establishment periods. Plantation shrub layer totals were lower than those found in either 5-year-old post-logging or mature aspen stands on good sites, 5-year-old aspen stands after fire, and mature stands of mixed pine-aspen-birch (table 3). Plantation totals were higher than shrub layer biomass in mature jack pine stands on shallow soils over bedrock. They were about the same as those found in similar conifer plantations and mature stands in the Isabella area and in naturally regenerating 5-year-old conifer stands after fire (table 3).

Table 3.--Mean biomass estimates (ovendry) of tall shrub layers from various studies in northeastern Minnesota

Source	Stand age (years)						
	1-5	6-10	11-15	16-20	21-25	26-30	Mature
	- - - - - - - - - - - - - Pounds/acre - - - - - - - - - - - - -						
This study[1]	2,034 (4)[2]	2,332 (9)	2,035 (13)	2,086 (9)	2,914 (9)	2,631 (9)	
Kernik[3]							
Plantations	1,202 (1)	230 (1)	2,265 (2)		2,276 (3)	2,339 (7)	
White cedar							1,331 (1)
Black spruce							2,747 (2)
Mixed red and white pine With subcanopy of aspen-birch							4,943 (1)
Ohmann and Grigal (1979)[4]							
Jack pine-fir	2,928 (1)						
Jack pine-oak	5,705 (1)						
Jack pine-black spruce	3,074 (1)						
Aspen-birch	15,387 (1)						
Silkworth (1980)[5]							
Aspen on good sites	32,834 (2)						3,729 (2)
Green (1979)[6]							
Jack pine on shallow soil							143
Jack pine on deep till							2,680 (15)

[1] Plantation conifer stands after clearcut harvest of jack pine-black spruce. Includes deciduous tree species under 1-inch d.b.h. and tall shrubs.

[2] Number of stands in parentheses.

[3] Personal communication. Plantation conifer stands after clearcut harvest of jack pine-black spruce, and mature uncut communities. Shrub layer includes deciduous tree seedlings under 1-inch d.b.h. and tall shrubs.

[4] Natural conifer (seed) and aspen (sucker) stands 5 years after fire. Shrub layer total includes deciduous trees and tall shrubs.

[5] Natural sucker stands after whole-tree harvest of aspen; uncut mature aspen stands on good sites. Shrub layer data includes regenerating aspen and tall shrubs 5 years after logging but includes tall shrubs only in the uncut stands.

[6] Mature, uncut, even-age jack pine stands more than 50 years old on either shallow soils over bedrock or on deep tills. The tall shrub layer data includes tall shrubs and tree seedlings. However, tree seedlings comprised a small proportion of the layer (a maximum of 8.6 pounds//acres in any stand). Most of the seedlings were decidous tree species.

Acer spicatum

Mountain maple was recorded in only 15 plantations, but was represented in all treatment categories. Probably because of its low occurrence, none of the treatments or treatment combinations explained a statistically significant amount of the variation in mountain maple biomass. RELEASE explained from 25 to 35 percent of the biomass variation, YEAR explained 9 to 16 percent, PREP explained 4 to 8 percent, and SPECIES explained 4 percent.

Above-average biomass values were associated with older plantations that had received only a disk treatment before planting; those that were planted to pine; and those that were released manually. Below-average biomass values were associated with plantations that had been prepared for planting by chemical methods or those that had been released from competing vegetation through a combination of manual plus chemical treatments.

Mountain maple is a prominent understory tall shrub or small tree of northern forest types. It grows in either sunlight or shade but does best where neither shade nor sunlight is extreme (Hosier 1974). The species reproduces most commonly by sprouting from underground stems, but it can also reproduce from seed, layered branches, and root suckers (Hosier 1974). Ground surface disturbance can eradicate mountain maple if the plants are uprooted and the stems severed. However, if the stems are simply tipped over or mashed down, or if they are just severed at the ground surface, sprouting will be stimulated (Hosier 1974). The species is resistant to foliar application of 2,4-D and 2,4,5-T herbicides (Benzie 1977). Herbicides can stimulate sprouting (Hosier 1974), but the shrub can be controlled by severing the stem and applying 2,4,5-T to the stump.

In a study of mature virgin forest communities of the region, mountain maple was recorded in 18 percent of jack pine-oak community-type stands, 29 percent of jack pine-black spruce stands, 71 percent of jack pine-fir stands, 77 percent of aspen-birch stands, and 100 percent of the maple-aspen-birch stands (Ohmann and Ream 1971). In this region, the species is apparently more representative of mesic conifer and hardwood communities than of dryer jack pine community-types. Mountain maple's minimal representation makes it difficult to develop strong conclusions about the species' response to silvicultural treatments. The shrub's biomass distribution is about what would be expected based on its known growth habits. Site preparation through chemical treatment and plantation release by manual plus chemical treatment would normally be expected to enhance sprouting rather than result in less biomass as found here, unless the herbicides were applied shortly after the stems of mountain maple were severed.

Alnus crispa

Green alder was tallied in 34 plantations and was represented in all treatment categories except plantations prepared by chemical methods and planted to spruce. The treatment YEAR was the dominant influence on green alder biomass. Treatment combinations YEAR-PREP-SPECIES, YEAR-PREP-RELEASE, and YEAR-SPECIES-RELEASE all explained a significant amount of the variation in green alder biomass. YEAR explained 46 to 53 percent of the variation in LEAF, TWIG, and STEM biomass. The other treatments explained less than 2 percent each.

Above-average biomass values were associated with 5- to 15-year-old plantations, and to a minor degree, those sites that had been prepared for planting to pine by rock-raking and later manual release from competing vegetation. The most adverse treatment category was chemical site preparation: the species was not recorded in those plantations in spite of its presence in other plantations of the same age category.

Green alder is a circumpolar species (Johnson 1968) common in the Lake Superior region (Rosendahl 1955). It is a common dominant understory shrub of conifer plantations in northeastern Minnesota (Peek *et al.* 1976). After establishment by seed, alders can spread or persist by sprouting, layering, underground stems, and suckers (Healy and Gill 1974). Alder is susceptible to both 2,4-D and 2,4,5-T herbicides (Arend and Roe 1961). Green alder's capacity for reproducing by vegetative means after disturbance and its susceptibility to herbicides may explain the biomass distribution found in this study. More biomass was found in intermediate-age plantations that were mostly prepared for planting by rock-raking (14 of 17 plantations in that time period) where alder could have responded to the disturbance by producing more aerial stems vegetatively. Less biomass was found in plantations subjected to chemical treatment.

Amelanchier spp.

Juneberry was sampled in 45 plantations and was represented in all treatment categories. The treatment combination YEAR-SPECIES-RELEASE explained a statistically significant amount of the variation in juneberry biomass. YEAR explained 18 to 20 percent of the LEAF, TWIG, and STEM biomass variation; SPECIES explained 14 percent; RELEASE explained 13 to 15 percent; and PREP explained 12 to 14 percent.

The treatment categories associated with above-average biomass values were: (1) older plantations that had been prepared for planting to pine by disking, (2) older plantations that had received no site preparation before planting, (3) plantations that had been manually released from competition, and (4) plantations where no release activity was recorded. The most important categories associated with less biomass were the chemically treated plantations, especially those receiving both chemical site preparation for planting spruce and also later chemical release. Shrubs of the genus *Amelanchier* grow most frequently in moist soils (Larson 1974), but some species of the genus are commonly found on upland sandy soils and dry rocky ridges. Juneberry is a common understory shrub of conifer forests and plantations in northeastern Minnesota (Lakela 1965, Peek *et al.* 1976). Juneberry reproduces by seed and from suckers. Although its growth and reproduction are best in full sunlight, it also tolerates shade (Larson 1974). Juneberry is resistant to 2,4-D herbicide but is susceptible to 2,4,5-T herbicide (Benzie 1977).

Consistent with the species' growth habits and response to management practices, more juneberry biomass was found in older plantations where it would have had time to recover from site disturbance (disk preparation for planting and manual plantation release). Juneberry biomass was also greater in those plantations that received no site preparation for planting. Less biomass was associated with plantations that received chemical treatment (assuming a mixture of D-T herbicide).

Betula papyrifera

White (paper) birch (<1 inch d.b.h.) was tallied in 19 plantations and was represented in all treatment categories except plantations treated with chemicals before planting spruce. The treatment combinations YEAR-PREP-SPECIES and YEAR-SPECIES-RELEASE explained a significant amount of the variation in birch biomass. YEAR explained from 48 to 55 percent of the variation, followed by PREP (3 to 15 percent), RELEASE (3 to 6 percent), and SPECIES (1 to 5 percent).

The most important treatment categories associated with above-average white birch biomass were 5- to 10-year-old plantations that had been prepared for planting by rock-raking and then later chemically released. The most important treatment categories associated with below-average birch biomass were older plantations that had received no site preparation with no subsequent release recorded. Because white birch is a tree species, the low biomass values associated with the older plantations probably show the growth of birch out of the 1-inch diameter class.

White (paper) birch, a widespread tree species in northern North America (Viereck and Little 1972), is common throughout the Lake States (Folwells 1965). It grows on a wide range of soils and soil moisture conditions, reproducing from seed (given a suitable seed bed) or from sprouts after cutting or fire (Folwells 1965), especially if the stems are less than 60 years old (Tubbs 1977). White birch is a fast-growing but short-lived tree that is normally replaced after one generation. However, in the northern Lake States, it may maintain itself through sprouting and gap replacement to become a component of mature fir-birch communities. White birch is susceptible to both 2,4-D and 2,4,5-T herbicides (Arend and Roe 1961).

More white birch biomass was found in plantations where site preparation and herbicide release were practiced; less biomass was found in plantations where no site preparation and/or release treatments were applied. These findings are consistent with birch's sprouting ability after disturbance and its need for mineral soil seedbeds. Absence of white birch in the three plantations chemically prepared for planting to spruce in the 1965-1969 period is consistent with the species' susceptibility to herbicides.

Cornus rugosa

Round-leaf dogwood was tallied in 13 plantations and was not represented in the youngest establishment period (1- to 5-year-old) or on sites prepared by chemical treatment for planting spruce. None of the treatment combinations explained a statistically significant amount of the variation in dogwood biomass. PREP explained 35 percent of the variation, followed by RELEASE (28 to 29 percent), YEAR (17 to 18 percent), and SPECIES (2 percent).

Older plantations that had been prepared for planting by a disk treatment and that later received a manual plus chemical or a chemical release contained above-average dogwood biomass. Younger plantations, sites prepared for planting by rock-raking or chemicals and plantations with no recorded release or only a manual release contained the least dogwood biomass. Thus, greater dogwood biomass is associated with less intensive site preparation and severe release; less dogwood biomass is associated with younger plantations, intensive site preparation, and least release.

Round-leaf dogwood is an infrequent understory shrub of many northern forest types, mostly dry to well-drained woodlands (Lesser and Wistendahl 1974) and rocky wooded slopes (Rosendahl 1955, Lakela 1965). In a study of nearby mature virgin forests, this species was recorded only in the more mesic hardwood and nonpine coniferous types (Ohmann and Ream 1971). In another study of 33-year-old post-fire communities in the area, round-leaf dogwood was recorded in the aspen-birch and birch communities but not in the jack pine-birch and jack pine communities (Ohmann *et al.* 1973). The distribution of dogwood biomass found here suggests that the shrub is not very tolerant to site disturbance (rock-raking) or canopy shade (less biomass in the plantations not released).

Corylus cornuta

Beaked hazel was tallied in 50 of the plantations and was represented in all treatment categories. The treatment PREP explained 15 percent of the biomass variation, followed by YEAR (14 percent), SPECIES (11 percent), and RELEASE (9 to 10 percent), for LEAF, TWIG, and WOOD.

The most important treatment categories associated with above-average biomass values were older plantations that had been prepared for planting to pine or a combination of pine and spruce by disking and later released only by manual methods or for which no release was recorded. The most important categories associated with below-average biomass values were younger plantations that had been chemically prepared for planting to spruce and/or later chemically released from competition.

Beaked hazel is a common understory species of conifer plantations in northeastern Minnesota (Peek *et al.* 1976). After initial establishment in a stand by seed, hazel can produce many aerial stems vegetatively from underground stems (Stearns 1974). Although it is a pioneer successional species that grows best where overhead shade allows more than 30 percent of full sunlight, it will persist in mature conifer stands on light soils (Stearns 1974), as in these plantations. Hazel is susceptible to chemical herbicides (Stearns 1974). Disk site preparation applied in midsummer turns up the underground organs of shrubs, setting back their growth for several years (Eyre and Zehngraff 1948). More hazel biomass was present in older plantations where hazel would have had sufficient time to recover from the disk site preparation treatment and where no chemicals were later applied for plantation release. Less hazel biomass was found in plantations that had received a chemical treatment to prepare the site for planting and/or to release the conifers after establishment.

Lonicera canadensis

Fly-honeysuckle was measured in 26 plantations and was represented in all but one treatment category (manual plus chemical release). None of the treatment combinations explained a statistically significant amount of the variation in honeysuckle biomass. The most important treatment was YEAR, but it explained only 9, 13, and 12 percent of the variation in LEAF, TWIG, and WOOD, respectively. RELEASE explained 6 to 8 percent, SPECIES 1 to 2 percent, and PREP 1 percent.

Treatment categories associated with above-average biomass values were 10- to 15-year-old plantations that had been prepared for planting to pine by rock-raking and that were manually released from competing vegetation. Categories associated with below-average biomass values were: (1) plantations older than 15 years, (2) more recent plantations that had been chemically prepared for planting to spruce, and (3) plantations chemically released from competing vegetation.

Fly-honeysuckle is an upright straggly shrub (Lakela 1965) found commonly throughout cool moist woods of the coniferous region (Rosendahl 1955). It is shade tolerant and can compete and persist under canopy shade, but it normally will not dominate a site (Jackson 1974). It can reproduce by seed and by shoots from a spreading root system (Jackson 1974).

Lonicera hirsuta

Hairy-climbing honeysuckle was tallied in 12 plantations and was not represented in the 1970-

1974 establishment period or in plantations released by a manual plus chemical combination. None of the treatment combinations explained a significant amount of the variation in honeysuckle biomass. PREP explained 32 to 41 percent of the variation in biomass, followed by YEAR (31 to 36 percent), SPECIES (3 to 20 percent), and RELEASE (8 to 11 percent).

The categories associated with greater biomass were older plantations that had received only a disk treatment or no site preparation before planting pine and plantations that received no release or only a manual release. The categories associated with less biomass were younger plantations that had been rock-raked (or chemical prepared before planting spruce), and later chemically released from competing vegetation.

Hairy-climbing honeysuckle is a high twining vine (Lakela 1965) that is common but not abundant in cool, moist coniferous forests on dry, well-drained soils (Grimm 1957, Van Dersal 1938). This shrub, a strong competitor that can persist under forest shade, can reproduce by seed or by shoots from a spreading root system (Jackson 1974).

Lonicera oblongifolia

Swamp fly-honeysuckle was recorded in 18 plantations and was represented in all treatment categories except the 1970-1974 establishment period and manual plus chemical release category. None of the treatments explained a significant amount of the variation in biomass. The lack of statistical significance is probably the result of its occurrence in few plantations. The most important treatment was YEAR, which explained 32 to 33 percent of the variation followed by PREP (18 to 19 percent), SPECIES (16 to 17 percent), and RELEASE (2 percent).

Above-average biomass was associated with 10- to 20-year-old plantations that had received no preparation or only a disk treatment before planting of pine and that were later chemically released from competing vegetation. Below-average biomass was associated with older plantations with plantations where no release was recorded, and with plantations that received only a manual release treatment.

Swamp fly-honeysuckle is a small, erect, somewhat straggly shrub that grows in moist habitats (Van Dersal 1938). It is common but not abundant in northern forests of this region (Rosendahl 1955). Here it was recorded in 34 percent of the plantations. It can reproduce from seed and by root suckers (Jackson 1974).

Because none of these honeysuckles normally dominate forest sites, little effort has been made to control them through management practices (Jackson 1974). This study suggests that the biomass distribution of these shrubs is influenced primarily by their susceptibility to chemical herbicides, and secondarily (at least for fly-honeysuckle and swamp fly-honeysuckle) by reduced growth and vigor as the plantation canopy closes and shade increases about 15 to 20 years after establishment.

Populus tremuloides

Quaking aspen (less than 1 inch d.b.h.) was represented in all treatment categories and recorded in 34 plantations. The treatment combinations YEAR-PREP-RELEASE and YEAR-SPECIES-RELEASE explained a significant amount of the variation in aspen biomass. YEAR explained 45 to 50 percent of the biomass variation. PREP explained 14 to 16 percent, RELEASE explained 6 to 9 percent, and SPECIES explained less than 1 percent.

Treatment categories associated with above-average biomass values were younger plantations, and to a lesser extent, those sites that had been prepared by rock-raking or disking, planting to pine, and later release by manual methods or for which no release was recorded. These latter categories were associated with younger plantations but not the youngest (1- to 5-year-old) plantation group. The most important categories associated with less biomass were the older plantations, plantations that had been chemically prepared for planting spruce, and plantations that had been chemically released from competing vegetation. The negative influence of age on aspen is probably a result of aspen growing out of the size class represented in this study. A separate analysis indicated that about 20 percent of the basal area and density of trees (greater than 1 inch d.b.h.) in the older plantations was attributable to deciduous hardwoods, mainly aspen and maple.

Aspen is a very common species and forest type throughout the Lake States (Brinkman and Roe 1975) and northeastern Minnesota (Grigal and Ohmann 1975, Ohmann and Ream 1971). It was recorded in 64 percent of the plantations studied here. Aspen is unique in that almost all stands originate as suckers that arise from existing root systems (Brinkman and Roe 1975). Aspen is an intolerant pioneer species that cannot reproduce successfully under its own shade. However, if aspen trees are present in the canopy, they can continue to produce suckers that serve as a reserve of aspen to regenerate a site after fire or logging. Aspen grows on a wide range of sites, from infertile sands to waterlogged mineral soils and peats (Brinkman and Roe 1975). Aerially applied 2,4-D herbicide during mid-July to mid-August will kill existing aspen trees and sprouts but will result in excellent resuckering the following year (Perala 1977). Controlling aspen when establishing a conifer plantation requires heavy mechanical disturbance or a herbicide site preparation, along with later successive herbicide or manual plantation releases (Perala 1977).

Aspen biomass was negatively associated with plantation age, with least biomass in the oldest plantations. Several factors may account for this trend: (1) the capability of aspen (a tree) to grow beyond the size-class category in this study (≥1 inch d.b.h.), (2) aspen shaded out by the conifers in older plantations, (3) fewer herbicide or release applications applied to younger plantations, increasing likelihood of resprouts, and (4) a positive association with rock-rake site preparation which was not practiced until 1960.

Prunus pensylvanica

Pin cherry was measured in 31 plantations and represented in all treatment categories. None of the treatment combinations was statistically significant. PREP explained 22 to 23 percent of the variation in biomass, followed by YEAR (18 percent), SPECIES (7 percent), and RELEASE (3 to 5 percent).

Above-average pin cherry biomass was associated with plantations between 5 and 25 years old that had been prepared for planting to pine by disk or rock-rake methods and later manually released from competing vegetation. Treatment categories associated with below-average pin cherry biomass were: (1) the very young plantations; (2) the oldest plantations that had undergone no site preparation before planting and no later release from competing vegetation; and (3) plantations where chemicals had been used to prepare the site for planting spruce.

Except for the lower biomass found in the 1- to 5-year-old plantations (where pin cherry was encountered in only one of the four plantations sampled) and the relatively high biomass with chemical release treatment, the distribution of pin cherry is consistent with what is known of its growth habits and response to management practices. Pin cherry is a common, fast-growing, short-lived, intolerant pioneer species of boreal forest ecosystems that declines about 25 to 35 years after disturbance (Marks 1974, Fulton 1974). Pin cherry usually becomes established after the logging of a mature forest. It grows from buried seed remaining in the forest floor from prior colonization or from prior dissemination by birds or small mammals (Marks 1974). Pin cherry is a common understory shrub in conifer plantations of northeastern Minnesota (Peek *et al.* 1976). It is very susceptible to 2,4-D or 2,4,5-T herbicides (Fulton 1974).

Prunus virginiana

Chokecherry was tallied in only 15 plantations but was represented in all treatment categories. None of the treatment combinations explained a statistically significant amount of the variation in any of the biomass classes. YEAR explained from 28 to 32 percent of the variation in biomass, followed by SPECIES (25 to 28 percent), PREP (18 to 22 percent), and RELEASE (9 to 10 percent).

Above-average biomass was associated with 5- to 10-year-old plantations that had been prepared by chemical treatment before planting spruce and older plantations that had received only manual release or where no release was recorded.

Chokecherry grows in a wide variety of soils and habitats throughout much of North America (Vilkitis 1974). It grows best in rich, well-drained, moist soil with adequate sunlight, but it is competitive and tolerant of shade and drought (Vilkitis 1974). Chokecherry is found commonly throughout northeastern Minnesota (Lakela 1965). The shrub was recorded in only 28 percent of the plantations of this study, and in only 25 percent of 33-year-old post-fire jack pine stands in an earlier study (Ohmann *et al.* 1973). Chokecherry reproduces by seed, but it also can sprout prolifically (Vilkitis 1974). The shrub may be somewhat resistant to both D and T herbicides (USDA 1961), but it is more susceptible to 2,4,5-T than to 2,4-D. For example, it was found in control plots but not in aerially treated (2,4,5-T herbicide) hardwood plots in northern Michigan (Gysel 1957).

This intermediate susceptibility to herbicides may explain the ambiguous result of more chokecherry biomass found in plantations prepared for planting by herbicide treatment and in older plantations receiving no herbicide release.

Rosa acicularis

Wild, prickly rose was represented in all treatment categories and recorded in 48 plantations. The treatment combinations YEAR-PREP-RELEASE and YEAR-SPECIES-RELEASE explained a significant amount of the variation in rose biomass. YEAR explained 17 to 19 percent of the variation in LEAF, TWIG, and STEM biomass; PREP explained 7 to 10 percent; SPECIES explained 7 to 9 percent; and RELEASE explained 5 percent.

Above-average biomass values were associated with 5- to 15-year-old plantations on sites that had been prepared by rock-raking, planted to a combination of pine and spruce, and later released from competition by manual plus chemical methods. Lower than average biomass values were associated with both the youngest and oldest plantations and with plantations that had been chemically prepared for planting to spruce.

Wild prickly rose is a circumboreal species that grows on a broad range of sites. It is common in conifer forests (Rosendahl 1955) and abundant as a successional species on disturbed areas (Densmore and Zasada 1977). After rose is established by seed, it can spread over wide areas vegetatively by rhizomes (Densmore and Zasada 1977). Because the degree of disturbance is important, rose was more abundant in nonscarified than in scarified conifer regeneration plots in interior Alaska (Zasada and Grigal 1978). In this case, the forest floor organic layers were totally removed by scarification, while there was rose vegetative reproduction from rhizomes on the relatively undisturbed organic layers of the nonscarified plots[1]. Rose is resistant to 2,4-D herbicide (Benzie 1977) but is susceptible to 2,4,5-T herbicide applied in May or June (Smithberg and Gill 1974). Rose was absent from northern Michigan plantations where 2,4,5-T herbicide was aerially applied (Gysel 1957).

The results of this study are generally consistent with known rose growth habits and response to management practices. More biomass was associated with sites prepared by rock-raking and those plantations treated by a manual plus chemical plantation release. If the herbicide was 2,4-D or if it was a D-T mixture but not effectively applied (applied in August), more biomass would occur. Manual release might involve severing some rose aerial stems that would produce more sprouts. More biomass following rock-raking as a site preparation treatment would not be likely unless the scraping did not remove all of the organic forest floor. Lower biomass would be associated with plantations prepared for planting by chemical treatment if, as is probable for site preparation purposes, the treatment was a 2,4-D and 2,4,5-T herbicide mixture applied in early summer.

Rubus strigosus

Raspberry was represented in all treatment categories and recorded in 51 sample plantations. The treatment combinations YEAR-SPECIES-RELEASE, and YEAR-PREP-RELEASE explained a significant amount of the variation in raspberry LEAF, TWIG, and WOOD biomass. YEAR explained from 36 to 44 percent of the biomass variation, followed by PREP (22 to 27 percent), RELEASE (16 to 17 percent), and SPECIES (7 to 8 percent).

Above-average biomass was associated with sites that had been chemically prepared for planting to spruce; and sites that were prepared by rock-raking and later chemically released. Below-average values were associated with older plantations with no site preparation and no later plantation release record.

These results are fully consistent with what is known about raspberry growth habits and the species' response to management practices. Raspberry is common in the forest types of this region (Rosendahl 1955). The species can reproduce from seeds, layers, sprouts, and underground stems (Core 1974). It grows better in partial shade than in full sunlight and can be rejuvenated by partial removal of overhead shade or deep cultivation (Core 1974). Scarification plots contained more raspberry than nonscarified conifer regeneration plots in interior Alaska (Zasada and Grigal 1978). Raspberry is resistant to 2,4-D herbicide (Benzie 1977). More raspberry biomass was found in younger plantations where herbicide was used to prepare sites for planting to spruce, where sites were rock-raked, and where it was used to release planted conifers. These practices reduce overhead shade but do not kill the resistant raspberry unless a combination of 2,4-D and 2,4,5-T is used. Management practices involving herbicides resulted in an increase in raspberry cover in Itasca State Park, Minnesota (Hansen *et al.* 1974). YEAR was the most important treatment. There was less raspberry biomass in older plantations where the ground was not disturbed before planting and where no release treatment was later applied to remove overhead shade.

Salix spp.

Willow was recorded in 24 plantations and was represented in all treatment categories except the youngest (1- to 5-year-old) plantations. None of the treatments explained a significant amount of the variation in biomass. In the case of LEAF and WOOD, RELEASE explained 23 and 24 percent of the variation in biomass, PREP 18 percent, YEAR 14 and 15 percent, and SPECIES 1 percent. In the case of TWIG, YEAR explained 31 percent, RELEASE 18 percent, PREP 18 percent, and SPECIES 2 percent.

Above-average biomass was associated with the oldest plantations that had received a disk treatment or no preparation before planting pine and that were later released by manual plus chemical or chemical methods. Below-average willow biomass was associated with: (1) younger plantations, (2) plantations that had received rock-rake or chemical site preparation (those planted to spruce), and (3) older plantations that had been given a manual release or where no release was recorded. To generalize, willow LEAF, TWIG, and STEM biomass was greatest in plantations receiving the least site preparation and the most release; willow biomass was lowest in plantations receiving the most site preparation and the least release.

Willows comprise a widely distributed genus with about 80 species throughout North America (Rosendahl 1955). At least 3 willow species grow in the study plantations: bebb willow (*S. bebbiana),* pussy willow (*S. discolor),* and upland willow (*S. humilis)* (Peek *et al.* 1976). Willows reproduce by seed, suckers, sprouts, and root shoots; are short-lived; and do best in good soils and full sunlight (Rawson 1974). Bebb willow grows both in moist and dry places; pussy willow is commonly found in swamps and other wet places, but it also grows well on dry soils; and upland willow is common on dry soils (Grimm 1957). Willows are susceptible to foliage application of 2,4-D and 2,4,5-T herbicides (Rawson 1974); however, they may resprout from the roots and stem base the season after treatment (USDA 1961). For example, Gysel (1957) found willow in both check and treatment plots after 2,4,5-T herbicide was aerially applied in northern Michigan.

More willow biomass associated with plantations receiving chemical release is consistent with the species' ability to reproduce vegetatively following such treatment.

CONCLUSIONS

Most of the responses to silvicultural practices found through this study are consistent with the ecological requirements of the species, at least to the extent that their requirements have been documented. The silvicultural goal of successful establishment and regeneration of conifer stands was met for these plantations, yet the stands contained tall shrub layers similar to those in conifer stands naturally regenerated after disturbance. The shrub layers were also similar to those found in several mature conifer forest communities in the area. Not surprisingly, the study plantations contained less shrub layer biomass than did either regenerating or mature aspen stands on better sites.

The effect of a persistent shrub layer on the long-term growth and yield of the planted conifers is irrelevant to the goal of successful re-establishment of the stand (thinning was not included in the study). The presence of a persistent shrub layer is, however, very important to the suitability of these plantations as wildlife habitat. Because a persistent shrub layer adds to both species and structural diversity, it is important not only to animals commonly thought of as browsers (deer, moose, and hare), but to invertebrate browsers and to many birds as well (Probst 1979).

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APPENDIX

This Appendix presents the results of the ANOVAs and Multiple Classification Analysis (fig. 1). It also includes more detailed tabular information on species biomass by treatment (Appendix tables 4-7).

Of the 96 three-way ANOVAs conducted, 38 LEAF, TWIG, or WOOD cases were significant at the $p = \geqslant 0.10$ level for one or more sources of variation: model, main effect, independent variable 1, independent variable 2, independent variable 3, overall interaction, interaction between variable 1 and 2, interaction between variables 1 and 3, and interaction between variables 2 and 3 (Appendix table 8). ANOVA main effects were significant at $p = \geqslant 0.10$ most often for YEAR-SPECIES-RELEASE with 4 times each for LEAF, TWIG, and WOOD; for YEAR-RELEASE-PREP with 3 times each for LEAF, TWIG, and WOOD; and for YEAR-PREP-SPECIES with 2 LEAF, 1 TWIG, and 2 WOOD instances (Appendix table 8). The treatments as individual sources of significant variation (as variables 1, 2, or 3 listed in the combination) showed YEAR to be most important with significant F-ratios for 9 LEAF, 11 TWIG, and 10 WOOD instances. PREP was significant once for LEAF and WOOD; SPECIES was significant once for TWIG and twice each for LEAF and WOOD; and RELEASE was significant for 2 LEAF, 1 TWIG, and 2 WOOD instances. Overall interaction effect was significant in YEAR-RELEASE-PREP twice each for LEAF, TWIG, and WOOD; YEAR-SPECIES-RELEASE was significant in 2 LEAF, 1 TWIG, and 3 WOOD instances; and YEAR-PREP-SPECIES was significant once for LEAF and WOOD. Interaction between YEAR and PREP was significant twice each for LEAF and WOOD and once for TWIG; interaction between YEAR and RELEASE was significant 7 times for LEAF, 5 times for TWIG, and 6 times for WOOD. PREP-RELEASE and YEAR-SPECIES interactions were significant once each for LEAF and WOOD, and SPECIES-RELEASE was significant once each for LEAF, TWIG, and WOOD (Appendix table 8).

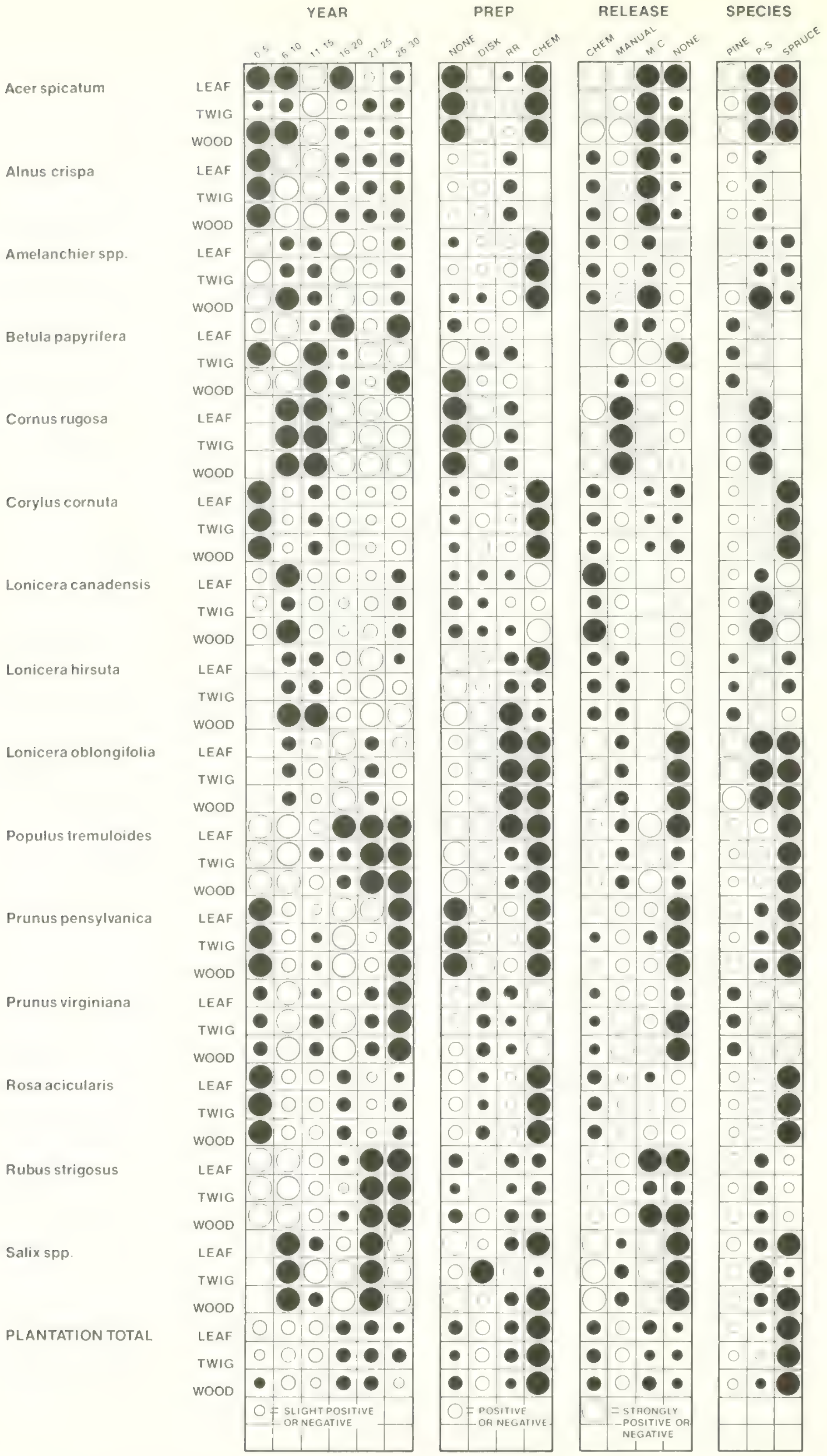

Figure 1.—*Diagrammatic representation of classification analysis results depicting the influence of silvicultural treatments on the major tall shrub and deciduous tree (under 1-inch d.b.h.) species in conifer plantations near Isabella, Minnesota. Shaded circles represent a negative influence and open circles represent a positive influence.*

Table 4.--Species and shrub layer total mean LEAF, TWIG, and WOOD biomass, standard error of the mean, and number of plantations for each establishment-period (YEAR) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the p=0.05 probability level[1/]

LEAF

Species	0-5 Years			6-10 Years			11-15 Years			16-20 Years			21-25 Years			26-30 Years			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	Pounds/acre																			
Acer rubrum				0.2	--	1	44.7	44.2	2	39.8	34.3	3	7.2	7.2	2					
Acer spicatum	22.0	11.4	3	18.1	9.2	3	36.6	36.5	2	8.1	3.5	2	17.2	9.4	4	36.7	--	1	0.1745	0.966
Alnus crispa	.3	--	1	251.6	110.5	4	110.7	33.6	7	52.9	26.6	7	129.8	43.3	7	83.8	21.3	8	6.0403	.001
Alnus rugosa													31.4	--	1					
Amelanchier spp.	22.5	--	1	10.5	4.8	9	15.5	5.2	9	26.1	5.6	7	25.8	8.3	8	26.8	9.7	9	1.7077	.157
Betula papyrifera	.9	--	1	7.1b	2.0	3	.7ab	.1	6	.7ab	.4	3	2.8ab	1.4	3	.3a	.1	3	2.8782	.058
Cornus rugosa				1.6	--	1	36.6	24.6	5	24.4	2.0	2	4.2	2.9	2	12.0	6.2	3	.4169	.792
Cornus stolonifera				23.2	--	1														
Corylus cornuta	47.9	24.9	3	78.5	31.3	8	85.4	21.2	13	95.3	17.0	9	84.6	66.5	8	45.0	31.8	9	1.4362	.230
Lonicera canadensis	2.4	--	1	1.2	.4	5	3.2	1.2	5	1.7	.7	5	2.7	1.2	5	2.7	1.4	5	.3934	.848
Lonicera dioica				.8	--	1														
Lonicera hirsuta				.7	.2	4	1.6	.7	3	2.1	.8	3	4.7	--	1	1.9	--	1	.9726	.479
Lonicera oblongifolia				.3	.2	4	2.1	1.9	4	.4	.2	2	.1	.1	2	.8	.4	6	1.5737	.240
Lonicera villosa				4.6	--	1	1.0	--	1							.7	--	1		
Populus balsamifera							5.6	--	1	.8	--	1	.1	--	1					
Populus tremuloides	257.3b	51.9	3	27.0ab	10.9	9	32.7ab	8.5	9	24.4ab	11.2	6	1.0a	.9	3	.8a	.6	4	4.5879	.004
Prunus pensylvanica	.6	--	1	14.0	5.7	6	8.8	3.3	10	11.9	7.4	4	9.6	2.8	4	5.1	4.3	6	1.0943	.388
Prunus virginiana	11.5	6.5	2	18.7	9.6	3	8.7	1.2	3	17.8	5.4	3	7.2	3.7	3	5.5	--	1	.8483	.549
Rhamnus alnifolia																15.1	--	1		
Ribes hirsuta																.1	--	1		
Ribes spp.				2.5	2.4	2				.1	--	1				.2	--	1		
Rosa acicularis	1.0	.9	2	6.3	2.5	9	9.0	2.5	12	5.8	2.2	8	5.3	1.1	8	4.1	.7	9	1.6749	.162
Rosa blanda				.2	--	1	3.3	1.2	3	.6	--	1				3.6	--	1		
Rubus parviflorus							55.3	--	1											
Rubus strigosus	52.6b	10.5	4	26.0b	6.9	9	23.4b	11.8	12	16.2ab	9.9	9	6.6a	4.5	8	4.9a	1.7	9	5.3600	.001
Salix spp.				9.1	5.4	7	25.6	16.8	5	47.5	34.0	4	4.9	4.5	3	46.2	5.0	5	.6256	.525
Sorbus americana				.1	--	1	5.4	--	1				2.1	--	1					
Viburnum rafinesquianum													8.3	--	1					
Plantation total shrub layer	311.2	91.2	4	83.1	90.3	9	66.0	43.8	13	48.4	39.0	9	24.9	98.7	9	96.7	39.6	9	.2183	.953

(Table 4 continued on next page)

(Table 4 continued)

Species	TWIG																		ANOVA	
	0-5 Years			6-10 Years			11-15 Years			16-20 Years			21-25 Years			26-30 Years			F	Proba-
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Ratio	bility
	Pounds/acre																			
Acer rubrum				3.1	--	1	34.5	30.6	2	22.3	19.2	3	17.5	17.3	2					
Acer spicatum	26.4	12.5	3	8.3	2.8	3	14.9	14.4	2	10.1	3.7	2	5.3	1.7	4	7.0	--	1	0.3356	0.879
Alnus crispa	.2	--	1	78.5	34.3	4	38.6	13.1	7	16.1	6.8	7	35.1	9.6	7	23.4	5.4	8	4.3735	[illegible]
Alnus rugosa													31.5	--	1					
Amelanchier spp.	6.2	--	1	2.9	1.3	9	4.4	1.4	9	7.3	1.5	7	7.0	2.1	8	7.4	2.7	9	1.6725	.166
Betula papyrifera	.1	--	1	2.7b	1.4	3	.1a	.1	6	.4ab	.3	3	2.3ab	2.2	3	.1ab	.1	3	3.1529	.044
Cornus rugosa				.4	--	1	7.7	5.1	5	5.2	.3	2	.9	.6	2	2.5	1.2	3	.4119	.796
Cornus stolonifera				3.6	--	1														
Corylus cornuta	11.2	6.0	3	13.8	7.5	8	20.5	4.6	13	23.5	4.0	9	41.6	14.3	8	33.7	7.0	9	1.5264	.201
Lonicera canadensis	1.0	--	1	.4	.2	5	1.2	.4	5	.5	.3	5	.9	.4	5	.8	.4	5	.6090	.694
Lonicera dioica				.3	--	1				.3	--	1								
Lonicera hirsuta				.3	.1	4	.5	.3	3	.9	.4	3	1.2	--	1	.9	--	1	.9152	.505
Lonicera oblongifolia				.2	.1	4	1.3	1.2	4	.2	.1	2	.1	.1	2	.4	.3	6	1.6277	.226
Lonicera villosa				.7	--	1	.4	--	1							.2	--	1		
Populus balsamifera							1.1	--	1				.1	--	1					
Populus tremuloides	28.3c	6.6	3	3.5bc	1.2	9	4.2bc	1.2	9	3.2bc	1.6	6	.3ab	.2	3	.3a	.1	4	5.5455	.001
Prunus pensylvanica	.5	--	1	4.1	1.5	6	2.1	.5	10	3.9	1.9	4	2.1	.5	4	1.2	.7	6	1.1099	.380
Prunus virginiana	2.5	1.7	2	4.0	2.5	3	1.4	.2	3	4.5	2.0	3	1.6	.9	3	1.2	--	1	.7251	.622
Rhamnus alnifolia																3.3	--	1		
Ribes hirsuta																.1	--	1		
Ribes spp.				1.1	1.1	2				.1	--	1				.1	--	1		
Rosa acicularis	.4	.4	2	2.9	1.1	9	3.9	1.1	12	2.5	1.0	8	2.2	.5	8	1.8	.4	9	1.8337	.127
Rosa blanda				.2	--	1	2.0	.7	3	.4	--	1				2.1	--	1		
Rubus parviflorus							70.2	--	1											
Rubus strigosus	14.6b	2.9	4	7.5b	1.8	9	5.6b	1.8	12	4.3ab	2.1	9	1.8a	1.1	8	1.4a	.4	9	7.1148	.001
Salix spp.				1.1	.6	7	3.1	2.1	5	5.7	4.1	4	.6	.5	3	5.5	3.1	5	2.1835	.110
Sorbus americana				.1	--	1	2.0	--	1				.6	--	1					
Viburnum rafinesquianum				.9	--	1														
Plantation total shrub layer	65.9	22.4	4	78.8	26.1	9	77.1	15.7	13	67.9	11.5	9	87.2	23.7	9	71.9	9.7	9	.1479	.980

(Table 4 continued on next page)

(Table 4 continued) WOOD

Species	0-5 Years Mean	0-5 Years SE	0-5 Years N	6-10 Years Mean	6-10 Years SE	6-10 Years N	11-15 Years Mean	11-15 Years SE	11-15 Years N	16-20 Years Mean	16-20 Years SE	16-20 Years N	21-25 Years Mean	21-25 Years SE	21-25 Years N	26-30 Years Mean	26-30 Years SE	26-30 Years N	ANOVA F Ratio	ANOVA Probability
	Pounds/acre																			
Acer rubrum				1.3	--	1	334.9	330.4	2	275.7	267.6	3	54.6	54.6	2					
Acer spicatum	347.5	178.0	3	199.0	73.3	3	383.7	380.5	2	140.0	55.1	2	153.2	67.8	4	304.4	--	1	0.1823	0.962
Alnus crispa	1.3	--	1	2085.6	917.1	4	876.6	251.6	7	447.7	238.0	7	1176.7	420.8	7	743.2	196.3	8	6.4638	.001
Alnus rugosa													311.8	--	1					
Amelanchier spp.	167.9	--	1	75.6	40.1	9	108.7	43.2	9	182.2	47.8	7	255.8	107.5	8	224.8	90.2	9	1.9014	.118
Betula papyrifera	2.8	--	1	67.8b	29.1	3	2.0ab	.4	6	7.8ab	6.7	3	34.3ab	32.1	3	.5a	.3	3	2.3526	.099
Cornus rugosa				4.1	--	1	150.3	109.8	5	87.8	7.5	2	13.5	10.3	2	51.5	27.6	3	.4210	.790
Cornus stolonifera													124.9	--	1					
Corylus cornuta	365.4	192.4	3	605.8	240.8	8	659.0	154.9	13	747.7	128.9	9	1371.3	480.6	8	1097.2	232.4	9	1.4901	.212
Lonicera canadensis	15.7	--	1	7.8	2.7	5	20.5	7.3	5	9.8	4.1	5	15.3	6.4	5	14.1	7.2	5	.5088	.766
Lonicera dioica				2.0	--	1				2.2	--	1								
Lonicera hirsuta				1.3	.4	4	2.4	1.2	3	18.1	14.0	3	11.7	--	1	15.1	--	1	.7849	.570
Lonicera oblongifolia				.8	.6	4	6.4	5.6	4	1.1	.6	2	.1	.1	2	2.3	1.2	6	1.5795	.238
Lonicera villosa				17.1	--	1	6.2	--	1							3.7	--	1		
Populus balsamifera							49.3	--	1				1.2	--	1					
Populus tremuloides	1414.9c	311.7	3	169.3bc	61.2	9	203.6bc	50.0	9	153.8bc	74.3	6	9.5	7.6	3ab	9.0a	5.4	4	5.3081	.002
Prunus pensylvanica	7.2	--	1	128.5	51.6	6	76.2	26.9	10	112.4	68.6	4	84.3	23.5	4	44.2	35.9	6	1.1120	.380
Prunus virginiana	59.4	42.4	2	95.9	60.8	3	31.7	4.4	3	113.4	50.2	3	39.5	22.2	3	29.0	--	1	.7167	.627
Rhamnus alnifolia																86.9	--	1		
Ribes hirsuta																.4	--	1		
Ribes spp.				22.8	22.7	2				.4	--	1				.8	--	1		
Rosa acicularis	2.1a	2.0	2	17.8ab	6.7	9	24.9b	6.9	12	16.0ab	7.0	8	13.0ab	2.8	8	10.5ab	2.5	9	1.9839	.101
Rosa blanda				.4	--	1	11.4	5.4	3	1.2	--	1				13.2	--	1		
Rubus parviflorus							70.2	--	1											
Rubus strigosus	89.0b	16.2	4	38.8b	10.3	9	40.6b	18.4	12	24.4ab	14.9	9	9.9a	6.9	8	7.4a	2.5	9	5.1676	.001
Salix spp.				55.7	37.5	7	230.5	175.0	5	481.3	381.2	4	28.3	27.2	3	410.1	231.2	5	.8485	.572
Sorbus americana				.2	--	1	45.7	--	1				12.4	--	1					
Viburnum rafinesquianum													32.4	--	1					
Plantation total shrub layer	1722.4	687.2	4	2043.5	730.3	9	1768.7	306.6	13	1837.7	238.7	9	2589.4	828.0	9	2333.7	318.1	9	.5480	.739

[1] Based on Student-Newman-Keuls test of those means indicated as significantly different by ANOVA.

Table 5.--Species and plantation shrub layer total mean LEAF, TWIG, and WOOD biomass, standard error of the mean, and number of plantations for each site-preparation (PREP) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the p=0.05 probability level[1]

LEAF

Species	None			Disk			Rockrake			Chemical			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Proba-bility
	Pounds/acre													
Acer rubrum	3.9	3.5	4	66.2	32.9	3				0.2	--	1		
Acer spicatum	30.0	22.1	3	21.0	7.9	5	19.5	6.9	6	3.4	--	1	0.3178	0.812
Alnus crispa	88.5	20.3	7	90.0	23.0	17	158.2	53.3	10				.1741	.841
Alnus rugosa	31.4	--	1											
Amelanchier spp.	24.6	9.0	9	23.8	4.7	19	17.0	4.5	12	2.7	1.1	3	1.9857	.132
Betula papyrifera	1.3	.8	5	11.1	.5	7	3.4	1.5	7				1.6443	.224
Cornus rugosa	6.2	5.1	4	40.7	23.3	5	12.5	6.7						
Cornus stolonifera										26.0	--	1		
Corylus cornuta	110.0ab	33.2	10	142.0b	27.8	21	83.8ab	16.7	17	6.7a	.7	2	2.6895	.057
Lonicera canadensis	2.1	1.1	4	2.4	.7	11	2.4	.7	9	1.4	.6	2	.0259	.994
Lonicera dioica				.8	--	1	.8	--	1					
Lonicera hirsuta	2.9	--	1	2.5	.7	5	.9	.3	5	.4	--	1	1.8857	.210
Lonicera oblongifolia	1.4	1.2	6	.8	.4	6	.3	.2	5	.1	--	1	1.0417	.405
Lonicera villosa	.7	--	1				2.8	1.9	2					
Populus balsamifera	.1	--	1				5.6	--	1					
Populus tremuloides	12.9	8.4	7	22.5	8.1	10	79.1	28.5	14	13.3	6.6	3	1.5956	.211
Prunus pensylvanica	2.6	1.6	6	9.8	3.4	11	12.8	3.4	13	.2	--	1	2.6862	.066
Prunus virginiana	11.2	2.3	2	11.2	3.3	7	9.5	2.3	5	38.0	--	1	1.0395	.413
Rhamnus alnifolia	15.1	--	1											
Ribes hirsuta				.1	--	1								
Ribes spp.				.2	.1	2				2.5	2.4	2		
Rosa acicularis	6.5	1.9	10	5.2	1.1	19	8.0	2.0	16	2.0	1.2	3	1.6219	.198
Rosa blanda	3.6	--	1	2.3	1.7	2	2.1	1.5	3					
Rubus parviflorus				55.3	--	1								
Rubus strigosus	5.7	2.1	10	12.4	4.8	20	34.9	8.8	18	31.9	13.1	3	4.7234	.006
Salix spp.	49.7	24.6	5	34.0 1	6.9	9	7.5	4.6	8	6.8	6.4	2	1.4070	.270
Sorbus americana	3.7	1.7	2				.1	--	1					
Viburnum rafinesquianum				8.3	--	1								
Plantation total shrub layer	240.3	52.4	11	316.9	43.8	21	310.3	46.3	18	83.2	7.3	3	3.0034	.039

(Table 5 continued on next page)

(Table 5 continued)

TWIG

Species	None			Disk			Rockrake			Chemical			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	Pounds/acre													
Acer rubrum	10.4	8.1	4	66.2	32.9	3				3.1	--	1		
Acer spicatum	12.2	8.7	3	8.2	1.4	5	16.8	7.2	6	4.0	--	1	0.1696	0.915
Alnus crispa	26.0	5.9	7	25.0	5.4	17	52.3	17.2	10				.2540	.777
Alnus rugosa	31.5	--	1											
Amelanchier spp.	6.8	2.4	9	6.6	1.2	19	4.7	1.2	12	.8	.4	3	2.0075	.129
Betula papyrifera	1.4	1.3	5	.2	.1	7	1.2	.8	7				.2213	.804
Cornus rugosa	1.3	1.1	4	8.5	4.8	5	2.7	1.4	4				2.7222	.114
Cornus stolonifera										3.6	--	1		
Corylus cornuta	25.1ab	7.2	10	33.3b	6.0	21	20.3ab	3.9	17	1.9a	.3	2	2.7763	.052
Lonicera canadensis	.7	.4	4	.7	.3	11	1.0	.3	9	.5	.2	2	.0942	.962
Lonicera dioica				.3	--	1	.3	--	1					
Lonicera hirsuta	1.0	--	1	1.1	.3	5	.3	.1	5	.2	--	1	1.6565	.252
Lonicera oblongifolia	.9	.8	6	.4	.3	6	.2	.1	5	.1	--	1	1.1089	.379
Lonicera villosa	.2	--	1				.5	.2	2					
Populus balsamifera	.1	--	1				1.1	--	1					
Populus tremuloides	1.7	1.0	7	2.9	1.1	10	9.2	3.1	14	1.9	1.0	3	1.8982	.151
Prunus pensylvanica	.8	.3	6	2.6	.8	11	3.4	.8	13	.3	--	1	2.5732	.075
Prunus virginiana	2.3	1.0	2	2.6	1.0	7	1.8	.6	5	8.9	--	1	.8378	.501
Rhamnus alnifolia	3.3	--	1											
Ribes hirsuta				.1	--	1								
Ribes spp.				.1	.1	2				1.1	1.1	2		
Rosa acicularis	2.8	.8	10	2.2	.5	19	3.5	.9	16	.9	.5	3	1.4843	.232
Rosa blanda	2.1	--	1	1.3	.9	2	1.2	1.0	3					
Rubus parviflorus				70.2	--	1								
Rubus strigosus	1.7	.5	10	3.4	1.1	20	8.3	1.7	18	8.7	3.1	3	5.9434	.002
Salix spp.	6.0	2.9	5	4.1	2.1	9	.9	.5	8	.8	.8	2	1.4211	.266
Sorbus americana	1.2	.6	2				.1	--	1					
Viburnum rafinesquianum				.9	--	1								
Plantation total shrub layer	65.7	16.2	11	84.7	11.6	21	80.9	13.5	18	21.8	1.3	3	2.7858	.051

(Table 5 continued on next page)

(Table 5 continued)

WOOD

Species	None			Disk			Rockrake			Chemical			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Proba-bility
	Pounds/acre													
Acer rubrum	30.1	26.4	4	495.4	246.5	3				1.3	--	1		
Acer spicatum	314.3	230.8	3	303.8	48.8	5	264.4	96.8	6	56.6	--	1	0.2755	0.842
Alnus crispa	771.8	180.3	7	799.4	218.6	17	1280.2	437.3	10				.1670	.847
Alnus rugosa	311.8	--	1											
Amelanchier spp.	203.6	86.0	9	197.1	52.0	19	129.8	39.3	12	12.9	5.2	3	1.8423	.156
Betula papyrifera	21.0	19.4	5	4.4	2.9	7	30.0	17.3	7				1.0956	.358
Cornus rugosa	26.4	23.1	4	168.2	104.6	5	41.4	22.7	4				2.6990	.116
Cornus stolonifera										124.9	--	1		
Corylus cornuta	822.0ab	240.4	10	1080.0b	201.5	21	651.2ab	127.2	17	56.6a	7.1	2	2.7413	.054
Lonicera canadensis	12.2	6.1	4	13.4	4.1	11	15.5	4.6	9	8.7	3.3	2	.0599	.980
Lonicera dioica				2.0	--	1	2.0	--	1					
Lonicera hirsuta	4.6	--	1	16.2	7.8	5	1.4	.6	5	1.0	--	1	1.3110	.336
Lonicera oblongifolia	4.4	3.7	6	2.4	1.2	6	1.0	.4	5	.1	--	1	1.0568	.399
Lonicera villosa	3.7	--	1				11.7	5.4	2					
Populus balsamifera	1.1	--	1				49.3	--	1					
Populus tremuloides	80.4	48.6	7	140.7	51.4	10	453.7	156.9	14	88.9	44.7	3	1.8766	.155
Prunus pensylvanica	23.6	13.9	6	88.3	30.1	11	113.6	29.1	13	1.9	--	1	2.7587	.062
Prunus virginiana	54.1	25.0	2	64.0	26.1	7	42.9	15.1	5	217.5	--	1	.8280	.505
Rhamnus alnifolia	86.9	--	1											
Ribes hirsuta				.4	--	1								
Ribes spp.				.5	.2	2				22.8	22.7	2		
Rosa acicularis	16.6	5.2	10	13.6	3.4	19	21.8	5.5	16	5.4	3.8	3	1.2490	.304
Rosa blanda	13.2	--	1	11.0	9.7	2	4.6	3.5	3					
Rubus parviflorus				70.2	--	1								
Rubus strigosus	8.5	3.0	10	18.7	7.3	20	53.1	13.6	18	48.0	19.8	3	4.5520	.007
Salix spp.	439.3	221.5	5	330.5	187.7	9	45.8	32.9	8	32.4	31.4	2	1.4041	.271
Sorbus americana	45.7	12.4	2				.2	--	1					
Viburnum rafinesquianum				32.4	--	1								
Plantation total shrub layer	1862.5a	439.3	11	2390.6a	353.0	21	2074.7a	360.6	18	370.1b	52.4	3	3.4705	.023

1/Based on Student-Newman-Keuls test of those means indicated as significantly different by ANOVA.

Table 6.--Species and plantation shrub layer total mean LEAF, TWIG, and WOOD biomass, standard error of the mean, and number of plantations for each release (RELEASE) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the p=0.05 probability level[1/]

LEAF

Species	Chemical			Manual			Manual-chemical			No record			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	- - -	- - -	- - -	- - -	- - -	- - -	Pounds/acre	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Acer rubrum	.4	.2	2	40.9	34.0	3	88.8	--	1	1.1	.2	2		
Acer spicatum	29.9	15.2	4	25.1	6.7	7	.1	--	1	6.8	3.5	3	1.2235	0.347
Alnus crispa	125.1	48.1	7	120.3	31.3	16	39.2	4.3	2	94.6	37.9	9	.0668	.997
Alnus rugosa				31.4	--	1								
Amelanchier spp.	17.1	6.2	13	24.0	5.3	18	7.0	6.2	2	21.7	5.1	10	1.9715	.134
Betula papyrifera	2.6	1.8	5	2.3	1.0	8	.7	--	1	1.2	.5	5	.1555	.924
Cornus rugosa	16.6	7.4	3	10.1	3.9	7	132.8	--	1	12.6	10.9	2	1.2234	.356
Cornus stolonifera	23.2	--	1											
Corylus cornuta	59.9	17.3	15	128.5	19.1	20	105.3	53.0	3	144.8	45.8	12	1.5490	.215
Lonicera canadensis	1.2	.4	5	2.9	.6	15				1.9	.6	6	.7334	.491
Lonicera dioica	.8	--	1							.8	--	1		
Lonicera hirsuta	1.4	.5	6	2.1	1.3	3				1.9	.4	3	.4138	.673
Lonicera oblongifolia	2.7	2.5	3	.4	.3	10				.4	.3	5	.1530	.560
Lonicera villosa				.9	.2	2	4.6	--	1					
Populus balsamifera	5.6	--	1	.1	--	1								
Populus tremuloides	28.5	11.1	14	51.7	33.0	10	37.5	20.3	2	59.0	32.9	8	.9606	.424
Prunus pensylvanica	8.4	3.9	9	10.8	3.0	15	8.6	3.2	2	7.1	5.0	5	.4693	.706
Prunus virginiana	12.0	4.4	7	14.1	3.1	4	10.9	--	1	11.8	7.6	3	.4178	.744
Rhamnus alnifolia				55.3	--	1								
Ribes hirsuta				.1	--	1								
Ribes spp.	2.5	2.4	2	.2	--	1				.1	--	1		
Rosa acicularis	6.2	2.1	15	6.1	1.2	20	7.5	3.3	3	6.0	1.7	10	.8390	.480
Rosa blanda				3.1	1.2	2	3.9	--	1	.4	.2	2		
Rubus parviflorus							55.3	--	1					
Rubus strigosus	36.5ab	9.6	16	13.1a	4.9	20	12.9a	10.3	3	12.0b	5.3	12	3.3412	.027
Salix spp.	37.2	16.9	9	23.2	15.4	9	29.1	--	1	5.1	3.3	6	2.0206	.143
Sorbus americana	5.4	--	1	1.1	1.0	2								
Viburnum rafinesquianum	4.3	--	1											
Plantation total shrub layer	221.2	40.1	17	321.9	40.8	21	314.5	128.4	3	305.1	67.6	13	1.1462	[illegible]

(Table 6 continued on next page)

(Table 6 continued)

TWIG

Species	Chemical			Manual			Manual-chemical			No record			ANOVA	
													F	Proba-
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Ratio	bility
	- - - - - -						Pounds/acre - - - -							
Acer rubrum	3.5	.4	2	31.8	17.5	3	65.1	--	1	3.1	.3	2		
Acer spicatum	21.5	7.8	4	10.6	4.3	7	.4	--	1	7.0	3.6	3	1.9206	0.195
Alnus crispa	40.9	16.4	7	36.8	9.8	16	12.2	4.4	2	25.8	8.3	9	.1279	.943
Alnus rugosa				31.5	--	1								
Amelanchier spp.	4.8	1.7	13	6.6	1.7	18	2.1	1.8	2	6.0	1.3	10	1.9794	.142
Betula papyrifera	1.2	1.1	5	1.1	.9	8	.1	--	1	.3	.2	5	.3409	.796
Cornus rugosa	3.6	1.6	3	2.1	.8	7	27.6	--	1	2.7	2.3	2	1.2226	.357
Cornus stolonifera	3.6	--	1											
Corylus cornuta	14.4	3.9	15	30.3	4.1	20	24.4	11.9	3	33.4	10.0	12	1.6760	.185
Lonicera canadensis	.4	.1	5	1.0	.2	15				.6	.2	6	1.0247	.375
Lonicera dioica	.3	--	1							.3	--	1		
Lonicera hirsuta	.5	.3	6	.7	.5	3				.7	.2	3	.4352	.660
Lonicera oblongifolia	1.7	1.6	3	.3	.2	10				.3	.2	5	.1220	.886
Lonicera villosa				.3	.1	2	.7	--	1					
Populus balsamifera	1.1	--	1	.1	--	1								
Populus tremuloides	3.7	1.2	14	6.5	4.0	10	4.8	2.1	2	6.3	3.1	8	.5879	.628
Prunus pensylvanica	2.2	1.0	9	2.9	.7	15	1.6	.8	2	2.1	1.1	5	.1727	.914
Prunus virginiana	2.4	1.1	7	3.0	.6	4	1.8	--	1	3.3	2.6	3	.3850	.766
Rhamnus alnifolia				3.3	--	1								
Ribes hirsuta				.1	--	1								
Ribes spp.	1.1	1.1	2	.1	--	1				.1	--	1		
Rosa acicularis	2.7	.9	15	2.6	.5	20	3.4	1.5	3	2.6	.8	10	.8198	.490
Rosa blanda				2.2	.7	3	2.2	--	1	.4	.2	2		
Rubus parviflorus							70.2	--	1					
Rubus strigosus	7.9	1.7	16	3.6	1.1	20	4.3	3.3	3	4.1	1.8	12	3.0553	.037
Salix spp.	4.5	2.1	8	2.8	1.9	9	10.8	--	1	.6	.4	6	1.5094	.243
Sorbus americana	2.0	--	1	.4	.4	2								
Viburnum rafinesquianum	.9	--	1											
Plantation total shrub layer	57.5	12.0	17	87.6	11.4	21	105.2	56.0	3	73.9	14.8	12	1.8328	.154

(Table 6 continued on next page)

(Table 6 continued)

WOOD

Species	Chemical			Manual			Manual-chemical			No record			ANOVA	
	Mean	SF	N	Mean	SE	N	Mean	SF	N	Mean	SF	N	F Ratio	Proba- bility
	Pounds/acre													
Acer rubrum	2.8	1.4	2	306.7	254.3	3	665.6	--	1	3.1	1.6	2		
Acer spicatum	373.7	151.3	4	256.5	74.0	7	3.1	--	1	103.6	54.9	3	1.3393	0.312
Alnus crispa	1017.9	385.3	7	1026.3	261.2	16	325.8	5.7	2	844.1	366.4	9	.0562	.982
Alnus rugosa				311.8	--	1								
Amelanchier spp.	126.6	53.3	13	207.1	58.7	18	37.5	35.0	2	172.2	46.1	10	2.3298	.089
Betula papyrifera	26.0	23.6	5	21.2	13.4	8	2.3	--	1	8.7	4.9	5	.1570	.924
Cornus rugosa	55.6	25.3	3	37.5	15.2	7	583.9	--	1	49.7	45.6	2	1.1836	.369
Cornus stolonifera	124.9	--	1											
Corylus cornuta	462.9	128.3	15	981.9	138.6	20	796.2	391.9	3	1092.8	333.9	12	1.6234	.197
Lonicera canadensis	7.0	1.9	5	16.9	3.8	15				11.0	3.6	6	.8908	.424
Lonicera dioica	2.0	--	1							2.0	--	1		
Lonicera hirsuta	9.0	7.4	6	4.6	3.6	3				8.6	3.7	3	.5951	.572
Lonicera oblongifolia	8.1	7.6	3	1.4	.7	10				1.4	.8	5	.1420	.869
Lonicera villosa				4.9	1.2	2	17.1	--	1					
Populus balsamifera	49.3	--	1	1.1	--	1								
Populus tremuloides	174.2	63.2	14	314.6	196.2	10	229.2	105.0	2	317.9	159.9	8	.6632	.581
Prunus pensylvanica	74.2	33.8	9	97.0	26.8	15	74.8	28.5	2	64.2	42.9	5	.4318	.732
Prunus virginiana	58.6	26.8	7	72.6	15.4	4	40.1	--	1	82.7	65.3	3	.3738	.774
Rhamnus alnifolia				96.9	--	1								
Ribes hirsuta				.4	--	1								
Ribes spp.	22.8	22.7	2	.8	--	1				.4	--	1		
Rosa acicularis	16.6	5.8	15	15.5	3.2	20	23.5	11.2	3	16.0	5.6	10	.7495	.529
Rosa blanda				8.9	2.5	3	20.7	--	1	.9	.4	2		
Rubus parviflorus							70.2	--	1					
Rubus strigosus	55.8a	14.9	16	19.7b	7.4	20	19.1ab	15.3	3	17.7b	7.8	12	3.3138	.028
Salix spp.	367.0	195.1	8	176.7	129.2	9	916.4	--	1	26.7	18.1	6	2.1176	.130
Sorbus americana	45.7	--	1	1.9	1.6	2								
Viburnum rafinesquianum	32.4	--	1											
Plantation total shrub layer	1441.2	314.1	17	2426.2	310.6	21	2051.2	846.9	3	2222.2	580.1	12	2.0020	.125

[1] Based on Student-Newman-Keuls test of those means indicated as significantly different by ANOVA.

Table 7.--Species and plantation shrub layer total mean LEAF, TWIG, and WOOD biomass, standard error of the mean, and number of plantations for each species planted (SPECIES) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the p=0.05 probability level[1]

LEAF

Species	Pine			Pine & Spruce			Spruce			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	Pounds/acre										
Acer rubrum	36.6	35.9	4	26.1	21.1	3	0.2	--	1		
Acer spicatum	20.2	4.9	11	30.0	22.1	3	3.4	--	1	0.2471	0.785
Alnus crispa	120.8	25.2	26	73.9	21.1	8				.0633	.803
Alnus rugosa				31.4	--	1					
Amelanchier spp.	24.8	4.1	30	13.5	3.2	10	2.7	1.1	3	3.4174	.043
Betula papyrifera	2.1	.8	14	1.6	.8	5				.1061	.749
Cornus rugosa	13.2	3.7	9	39.9	31.4	4				.1890	.672
Cornus stolonifera							23.2	--	1		
Corylus cornuta	116.0	18.7	36	110.9	26.2	12	6.7	.7	2	2.8724	.067
Lonicera canadensis	2.5	.5	19	1.8	.9	5	1.4	.6	2	.0805	.932
Lonicera dioica	.8	.8	2								
Lonicera hirsuta	1.7	.4	10	2.9	--	1	.4	--	1	1.1279	.366
Lonicera oblongifolia	.6	.2	11	1.3	1.2	6	.1	--	1	1.3898	.279
Lonicera villosa	2.7	2.0	2	1.0	--	1					
Populus balsamifera	2.8	2.8	2								
Populus tremuloides	50.3	17.2	25	27.7	10.5	6	13.3	11.4	3	.0207	.980
Prunus pensylvanica	10.9	2.4	24	4.5	2.3	6	.2	--	1	1.0844	.352
Prunus virginiana	9.4	1.5	12	17.7	8.8	2	38.0	--	1	2.3458	.138
Rhamnus alnifolia	15.1	--	1								
Ribes hirsuta	.1	--	1								
Ribes spp.	.2	--	1	.1	--	1	2.5	2.4	2		
Rosa acicularis	6.1	1.1	34	7.7	2.1	11	2.0	1.2	3	2.3263	.109
Rosa blanda	2.9	1.4	3	1.9	1.1	3					
Rubus parviflorus				55.3	--	1					
Rubus strigosus	23.5	5.3	37	6.0	1.6	11	31.9	13.1	3	2.0072	.146
Salix spp.	28.8	11.2	17	24.9	16.9	5	6.8	6.4	2	.0549	.947
Sorbus americana	.1	--	1	3.7	1.6	2					
Viburnum rafinesquianum	8.3	--	1								
Plantation total shrub layer	311.6a	32.0	38	253.8ab	50.8	12	83.2b	7.3	3	3.2543	.047

(Table 7 continued on next page)

(Table 7 continued)

TWIG

Species	Pine			Pine & Spruce			Spruce			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Proba-bility
	Pounds/acre										
Acer rubrum	22.5	19.1	4	25.9	15.3	3	3.1	--	1		
Acer spicatum	12.8	4.1	11	12.2	8.7	3	4.0	--	1	0.2676	0.770
Alnus crispa	36.5	7.7	26	22.8	5.9	8				.0452	.833
Alnus rugosa				31.5	--	1					
Amelanchier spp.	6.9a	1.1	30	3.8ab	.9	10	.8b	.4	3	3.4666	.041
Betula papyrifera	.6	.4	14	1.6	1.3	5				.1733	.682
Cornus rugosa	2.8	.8	9	8.3	6.5	4				.1895	.672
Cornus stolonifera							3.6	--	1		
Corylus cornuta	27.2	4.1	36	26.3	5.8	12	1.9	.3	2	2.8590	.067
Lonicera canadensis	.9	.2	19	.6	.3	5	.5	.2	2	.1843	.833
Lonicera dioica	.3	.3	2								
Lonicera hirsuta	.7	.2	10	1.0	--	1	.2	--	1	.7010	.521
Lonicera oblongifolia	.4	.2	11	.9	.8	6	.1	--	1	1.4783	.259
Lonicera villosa	.4	.3	2	.4	--	1					
Populus balsamifera	.5	.5	2								
Populus tremuloides	6.0	2.0	25	3.5	1.2	6	1.9	1.0	3	.0229	.977
Prunus pensylvanica	2.7	.6	24	1.9	.7	6	.3	--	1	1.0575	.361
Prunus virginiana	1.9	.4	12	4.8	3.6	2	9.0	--	1	2.0474	.172
Rhamnus alnifolia	3.3	--	1								
Ribes hirsuta	.1	--	1								
Ribes spp.	.1	--	1	.1	--	1	1.1	1.1	2		
Rosa acicularis	2.6	.4	34	3.3	1.0	11	.9	.5	3	2.1162	.132
Rosa blanda	1.8	.9	3	1.1	.6	3					
Rubus parviflorus				70.2	--	1					
Rubus strigosus	5.7	1.1	37	1.9	.4	11	8.7	3.1	3	2.1858	.124
Salix spp.	3.5	1.3	17	3.0	2.1	5	.9	.9	2	.2128	.810
Sorbus americana	.1	--	1	1.2	.6	2					
Viburnum rafinesquianum	.9	--	1								
Plantation total shrub layer	79.0a	8.4	38	79.6a	18.4	12	21.8b	13	3	2.5502	.088

(Table 7 continued on next page)

(Table 7 continued) WOOD

Species	Pine Mean	Pine SE	Pine N	Pine & Spruce Mean	Pine & Spruce SE	Pine & Spruce N	Spruce Mean	Spruce SE	Spruce N	ANOVA F Ratio	ANOVA Probability
	Pounds/acre										
Acer rubrum	273.8	268.5	4	196.2	158.4	3	1.3	--	1		
Acer spicatum	236.8	55.5	11	314.3	230.8	3	56.6	--	1	0.2774	0.762
Alnus crispa	1027.9	216.0	26	633.4	188.7	8				.0492	.826
Alnus rugosa				311.8	--	1					
Amelanchier spp.	205.9	42.4	30	95.7	22.7	10	12.9	5.2	3	3.1019	.056
Betula papyrifera	15.7	9.2	14	25.1	18.7	5				.8261	.376
Cornus rugosa	47.1	13.2	9	172.1	139.0	4				.2099	.656
Cornus stolonifera							124.9	--	1		
Corylus cornuta	819.9	8.5	36	849.7	192.2	12	56.6	7.1	2	2.8658	.067
Lonicera canadensis	14.9	3.1	19	10.5	5.1	5	8.7	3.3	2	.1382	.872
Lonicera dioica	2.0	2.0	2								
Lonicera hirsuta	8.8	4.5	10	4.6	--	1	1.0	--	1	.1550	.859
Lonicera oblongifolia	1.9	.6	11	4.2	3.8	6	.1	--	1	1.4133	.274
Lonicera villosa	10.3	6.8	2	6.2	--	1					
Populus balsamifera	25.2	24.2	2								
Populus tremuloides	292.6	96.0	25	167.9	59.8	6	88.9	44.7	3	.0152	.985
Prunus pensylvanica	97.3	21.0	24	42.5	21.4	6	1.9	--	1	1.1314	.337
Prunus virginiana	44.2	8.3	12	120.6	91.4	2	217.5	--	1	2.0350	.173
Rhamnus alnifolia	86.9	--	1								
Ribes hirsuta	.4	--	1								
Ribes spp.	.8	--	1	.4	--	1	22.8	22.7	2		
Rosa acicularis	16.1	2.9	34	20.6	6.3	11	5.4	3.8	3	1.7079	.193
Rosa blanda	8.4	4.0	3	8.0	6.3	3					
Rubus parviflorus				70.2	--	1					
Rubus strigosus	35.6	8.1	37	8.9	2.5	11	48.0	19.8	3	1.9290	.156
Salix spp.	258.9	113.8	17	227.5	176.0	5	32.4	31.4	2	.0380	.963
Sorbus americana	.2	--	1	29.1	16.6	2					
Viburnum rafinesquianum	32.4	--	1								
Plantation total shrub layer	2256.5a	258.1	38	1857.5a	393.5	12	370.1b	52.4	3	4.0553	.023

[1] Based on Student-Newman-Keuls test of those means indicated as significantly different by ANOVA.

Table 8.--F-ratio and probability values for significant (p=<0.10) shrub layer LEAF, TWIG, and WOOD biomass 3-way ANOVA tests for treatment combinations applied to conifer plantations near Isabella, Minnesota

Species/ANOVA tests	Source of variation																	
	Model			Main effects			Independent Variable 1			Independent Variable 2			Independent Variable 3			Interaction		
	Leaf	Twig	Wood	Leaf	Twig	Wood	Leaf	Twig	Wood	Leaf	Twig	Wood	Leaf	Twig	Wood	Leaf	Twig	Wood
Alnus crispa																		
YEAR-PREP-RELEASE	3.741	3.620	3.832	4.633	4.284	4.817	9.013	8.142	9.402							2.625	2.788	2.600
	.007	.008	.006	.004	.006	.003	.001	.001	.001							.051	.041	.053
YEAR-PREP-SPECIES	2.360		2.529	3.124	2.483	3.349	4.837	3.809	5.194									
	.042		.031	.016	.044	.012	.004	.012	.003									
YEAR-SPECIES-RELEASE	4.035	3.804	4.100	5.489	4.938	5.666	9.717	8.638	10.061							2.582	2.671	2.534
	.004	.006	.004	.002	.003	.002	.001	.001	.001							.050	.045	.054
Amelanchier spp.																		
YEAR-SPECIES-RELEASE	1.940	1.897	2.136	2.108	2.064	2.336				2.820		2.640						1.955
	.068	.075	.045	.072	.078	.049				.082		.095						.090
Betula papyrifera																		
YEAR-PREP-SPECIES	6.406		4.390	5.881		4.116	5.446	3.204	3.328				5.952		6.040	7.806		5.121
	.011		.030	.015		.039	.023	.080	.074				.045		.044	.012		.035
YEAR-SPECIES-RELEASE								3.975			4.138							
								.078			.096							
Corylus cornuta																		
YEAR-PREP-RELEASE																		
Populus tremuloides																		
YEAR-PREP-RELEASE		2.119	2.162	2.332	2.760	2.778	2.796	3.521	3.472									
		.078	.073	.069	.038	.038	.059	.029	.030									
YEAR-SPECIES-RELEASE				2.330	2.848	2.856	3.765	5.027	4.961									
				.091	.050	.050	.031	.012	.013									
Rosa acicularis																		
YEAR-PREP-RELEASE								2.136	2.205									
								.093	.084									
YEAR-SPECIES-RELEASE							2.225	2.375	2.424									
							.082	.067	.062									
Rubus strigosus																		
YEAR-PREP-RELEASE	4.601	4.304	4.760	5.750	5.955	5.819	3.244	3.646	3.312				4.312	3.101	4.500	3.547	2.790	3.790
	.001	.001	.001	.001	.001	.001	.020	.012	.018				.013	.043	.011	.003	.013	.002
YEAR-SPECIES-RELEASE	3.567	3.591	3.552	5.403	5.990	5.305	6.324	7.701	6.195				2.719		2.783	2.151		2.204
	.001	.001	.001	.001	.001	.001	.001	.001	.001				.064		.060	.045		.040
Plantation total																		
YEAR-PREP-RELEASE										2.556		2.309						
										.075		.097						

Interaction Independent Variables 1-2			Interaction Independent Variables 1-3			Interaction Independent Variables 2-3		
Leaf	Twig	Wood	Leaf	Twig	Wood	Leaf	Twig	Wood
			3.808	3.490	3.938			
			.033	.042	.030			
			3.570	3.759	3.480			
			.021	.017	.023			
			2.388	2.326	2.626	3.775	3.730	3.874
			.058	.063	.041	.040	.041	.037
9.712		3.845	10.504		10.006			
.010		.075	.014		.016			
			2.419	2.393	2.406			
			.054	.056	.055			
11.863	10.593	12.532	2.921		3.214	4.050	3.252	4.463
.001	.001	.001	.025		.016	.011	.027	.007
			2.742	2.207	2.815			
			.020	.054	.018			
			2.153					
			.077					

☆U S GOVERNMENT PRINTING OFICE 1982– 566-928 93

Ohmann, Lewis F.
Tall shrub layer biomass in conifer plantations of northeastern Minnesota. Res. Pap. NC-219. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 30 p.

Provides estimates of biomass (pounds/acre) for tall shrub species in 53 conifer plantations in northeastern Minnesota. The estimates are analyzed by plantation age and silvicultural practices used to establish and release the plantations.

KEY WORDS: site preparation, plantation release, silviculture, herbicide, biomass estimation.

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-220**

Tree Biomass in the North Central Region

Gerhard K. Raile and Pamela J. Jakes

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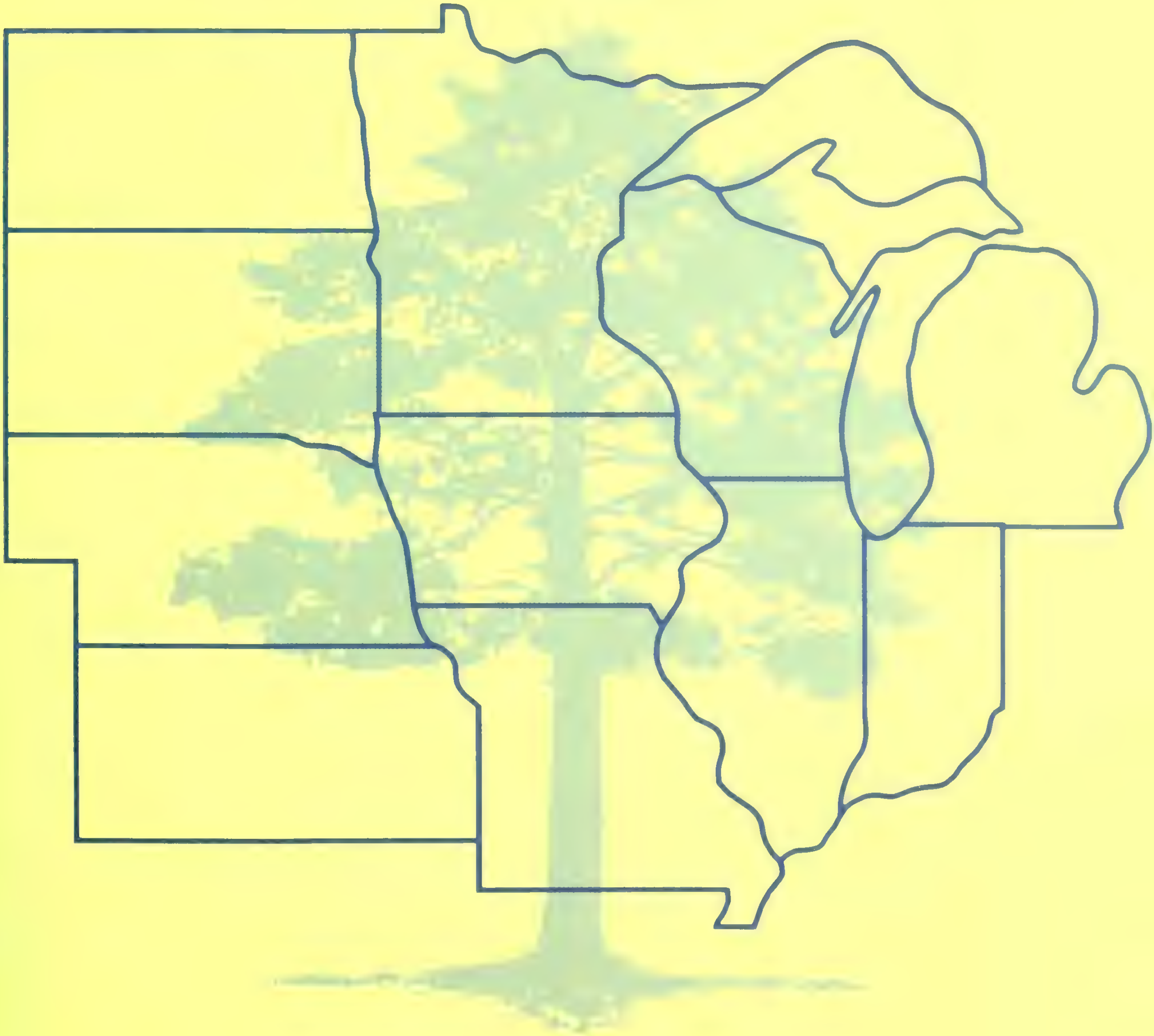

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication April 12, 1982
1982

FOREWORD

Resources Evaluation is a continuing endeavor as mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA). Its objective is to periodically inventory the Nation's forest land to determine its extent, condition, and volume of timber, growth, and depletions. This kind of up-to-date information is essential to frame intelligent forest policies and programs. USDA Forest Service regional experiment stations are responsible for conducting these inventories and publishing summary reports for individual States. The North Central Forest Experiment Station is responsible for evaluating the forest resources of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Eastern South Dakota, and Wisconsin.

Resource bulletins analyzing findings from the most recent forest inventory are available from the Station for most north central States. Updated 1977 forest statistics for each State are found in the RPA assessment document, "An Analysis of the Timber Situation in the United States 1952-2000," available from USDA Forest Service, Washington, D.C.

The following North Central Forest Experiment Station office personnel assisted in preparing the tables and manuscript:

Mary Jean Hanson, Secretary;
Patrick Peine, Statistical Assistant; and
Joan Stelman, Statistical Assistant.

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TREE BIOMASS IN THE NORTH CENTRAL REGION

Gerhard K. Raile, *Associate Mensurationist,*
and **Pamela J. Jakes,** *Associate Resource Analyst*

Recent changes in the Nation's forest resource picture have forced recognition of whole-tree utilization as a viable forestry practice. Increasing demand for wood fiber, increasing harvesting and production costs, and increasing interest in alternative forms of energy are just a few of the developments that have spurred interest in total aboveground tree volume.

This interest is becoming evident in the North Central Region. The Minnesota Department of Natural Resources and the Minnesota Energy Agency have released a report on the feasibility of using wood biomass for energy (Minnesota Department of Natural Resources 1980). The study concluded that in Minnesota, wood "could supply a substantial portion of the energy needed for residential heating now and in the future." A study released by the Lake Superior Basin Studies Center presents a plan for utilizing Populus species (particularly aspen) in the upper Great Lakes States (Wood 1980). The report includes an analysis of the use of aspen for food, direct combustion, gasification, and alcohol production. In a 1975-1976 study of Minnesota logging utilization factors, five logging firms were producing whole tree chips—in the previous study, dated 1960-1961, no firms had whole tree chip operations (Blyth and Smith 1980).

Until recently, timber management and wood procurement decisions could not be made on a whole tree basis because only traditional measures of merchantable volume in cubic and board feet were available. What was needed was a way to estimate the amount of wood and bark contained in the whole tree, including the crown.

A biomass committee has been formed through the Renewable Resources Evaluation (RRE) Projects at USDA Forest Service forest experiment stations to estimate aboveground tree volume (in green tons) on commercial forest land[1] nationwide using current state-of-the-art methodology.[2] This is a first step in including estimates of tree biomass in standard forest inventory efforts. The RRE Project at the North Central Forest Experiment Station estimated tree biomass on commercial forest land in 11 States—Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Eastern South Dakota, and Wisconsin. For each State, tree biomass was estimated by (1) softwoods and hardwoods and biomass component, (2) species groups and diameter class, and (3) softwoods and hardwoods and ownership class. A summary of a methodology for quantifying the biomass and estimates of the biomass for the North Central Region are presented here.

METHODS

Equations are currently available that estimate tree biomass, however, these equations were unacceptable for estimating tree biomass in the North Central Region. First, many of the equations require data unavailable for most of the north-central States. Data limitations in most States made it necessary to develop equations requiring only the number of growing-stock[3] and cull[4] trees by 2-inch diameter class.

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[1] *Commercial forest land is forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation.*

[2] *Bones, James. 1980. Unpublished study plan--A plan for compiling aboveground tree biomass estimates for the United States. On file at the North Central Forest Experiment Station, Renewable Resources Evaluation Project.*

Second, some existing equations give unreliable estimates outside the range of the data used to fit the equations. For large diameter trees in particular, different equations give widely different estimates of tree biomass.

Finally, most of the existing equations do not estimate weight by components as defined by the RRE Projects. RRE estimates of tree biomass include the bark, and are made up of five components:

1. Growing-stock bole—the aboveground volume of growing-stock trees 5 inches or more in diameter from a 1-foot stump to a variable 4-inch diameter top;
2. Growing-stock top and limbs—the aboveground volume of growing-stock trees 5 inches or more in diameter from a 1-foot stump, excluding the growing-stock bole;
3. Cull tree bole—the aboveground volume of cull trees 5 inches or more in diameter from a 1-foot stump to a fixed 4-inch diameter top;
4. Cull tree top and limbs—the aboveground volume of cull trees 5 inches or more in diameter from a 1-foot stump, excluding the cull bole;
5. 1- to 5-inch trees—the total aboveground volume of all trees 1 to 5 inches in diameter.

Data available from State-wide forest inventories for estimating tree biomass vary across the Region; therefore, it is necessary to use two different methods for estimating tree biomass—one for North Dakota and Minnesota and another for all other States.

North Dakota and Minnesota: New forest inventories in North Dakota (1980) and Minnesota (1977)[5] enabled us to use gross cubic foot volume, net cubic foot volume, and bark correction factors[6] to estimate tree biomass. For each tree, the net cubic foot volume in the bole was converted to green tons using weight conversion factors for individual species (Markwardt 1930). Then, the weight of the bole bark was computed using bark correction factors for each species and an average bark weight of 37 pounds per cubic foot. The weight in the tops and limbs of growing-stock and cull trees was estimated as 45 percent of the gross bole weight (Young *et al.* 1976). Finally, the biomass for trees from 1 to 5 inches in diameter was computed by a regression equation fit to Young's tree weight table (Young *et al.* 1976). This regression equation used d.b.h. (diameter at breast height) to estimate total aboveground tree biomass as 80 percent of the total above- and belowground biomass.

All other States: Data from the 1977 Assessment for the Renewable Resources Planning Act (RPA) and the most recent State inventories were used to determine the number of growing-stock and cull trees by species group and 2-inch diameter class (USDA Forest Service 1980). For each species group in each State, biomass by component and 2-inch diameter class was computed for all trees at least 1 inch in diameter using the following equation:

$$W = A(\text{d.b.h.})^B$$

where W is the component weight in green tons per tree and A and B are regression parameters.

Nonlinear regression techniques were used with biomass data from Minnesota, North Dakota, and Wisconsin to determine the regression parameters[7] (table 1).

RESULTS

Tree biomass in the North Central Region totals 3.6 billion tons. The distribution of tree biomass among biomass components is different for softwoods and hardwoods (table 2). For softwoods, 23 percent of the total tree biomass is in from 1- to 5-inch trees, but this component accounts for only 15 percent of the total tree biomass for hardwoods (fig. 1). A larger percentage of the hardwood tree biomass is in cull trees (17 percent) than for softwoods (5 percent).

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[3] *Growing-stock trees are all live trees 1-inch d.b.h. and larger, except cull trees.*

[4] *Cull trees are rotten or rough trees. Rotten trees are live trees 1-inch d.b.h. and larger of commercial species that do not contain a merchantable 12-foot saw log, now or prospectively, because of rot. Rough trees are live trees of any size that do not contain at least one merchantable 12-foot saw log, now or prospectively, because of roughness, poor form, or noncommercial species.*

[5] *Includes 1979 data for the Superior National Forest.*

[6] *Unpublished data on file at the North Central Forest Experiment Station, Renewable Resources Evaluation Project.*

[7] *Biomass data from these three States consisted of green weight by biomass component, species group, and 2-inch diameter class. Data from the 1968 Wisconsin inventory were used for cottonwood and hemlock.*

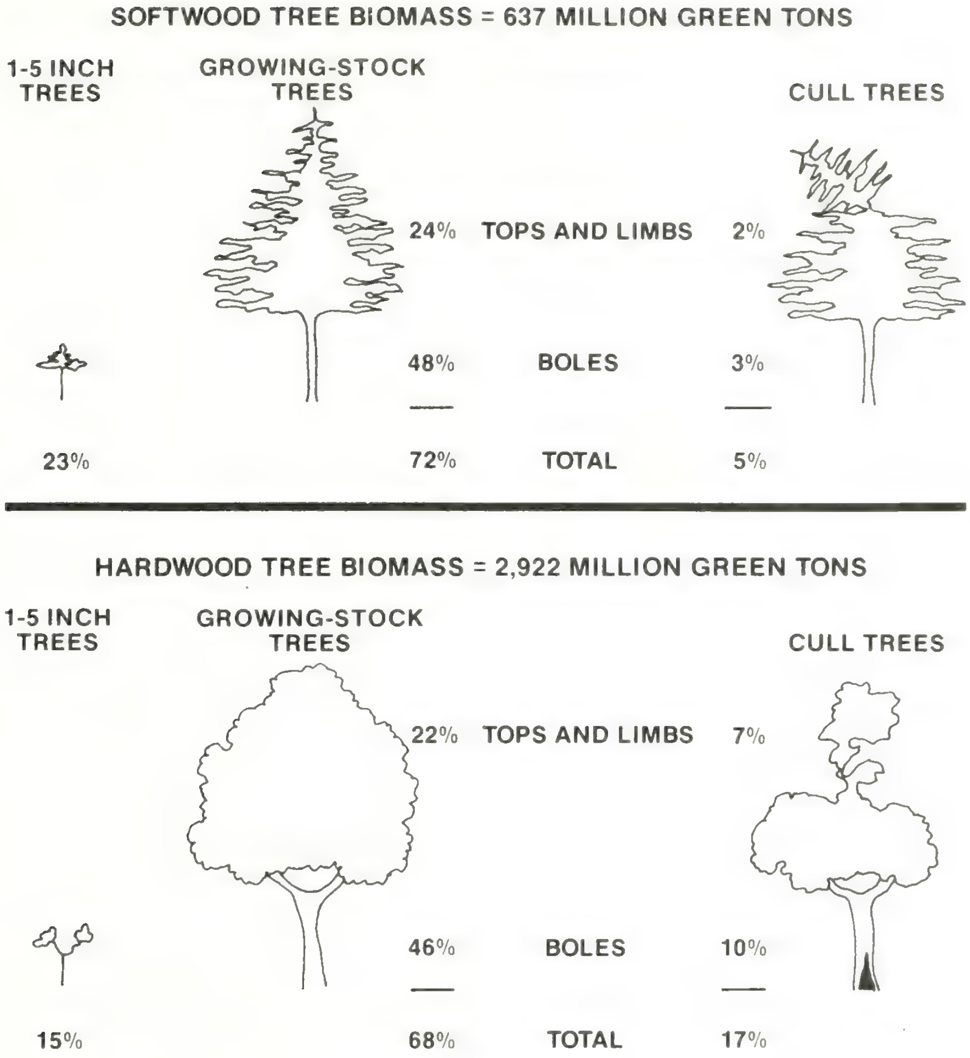

Figure 1.—*Distribution of the biomass by softwoods and hardwoods and biomass components, North Central Region.*

The distribution of tree biomass among components also varies by geographic unit (fig. 2). In the Lake States (Michigan, Minnesota, and Wisconsin), where a large portion of the region's softwood trees are found, only 12 percent of the total tree biomass is in cull trees. In the units in which hardwoods account for a large portion of the total number of trees, a larger portion of the total tree biomass is in cull trees—21 percent of the tree biomass in the Central States (Illinois, Indiana, Iowa, and Missouri) is in cull trees as is 36 percent in the Prairie States (Kansas, Nebraska, North Dakota, and Eastern South Dakota).

The average tree biomass per acre of commercial forest land in the North Central Region is 50 tons. Average tree biomass per acre by State ranges from a low of 45 tons per acre in Illinois to a high of 57 tons per acre in Indiana.

In the Central States, the oaks account for the majority of the tree biomass (table 3). Of the 1,049 million green tons found in the Unit, 303 million tons are white oaks and 276 million tons are red oaks. Softwoods total only 33 million green tons, most of which is found in loblolly and shortleaf pine species.

Although a larger portion of the tree biomass in the Lake States Unit is in softwoods than in the other units, hardwoods still make up a majority of the total. Of the 2,386 million tons of total biomass, 1,794 million are in hardwoods. Aspen and cottonwood species account for 369 million tons, hard maple for 252 million, red oak for 245 million, and birch for 243 million (table 4). Softwood tree biomass totals 591 million green tons, with balsam fir accounting for 136 million green tons and jack pine for 104 million.

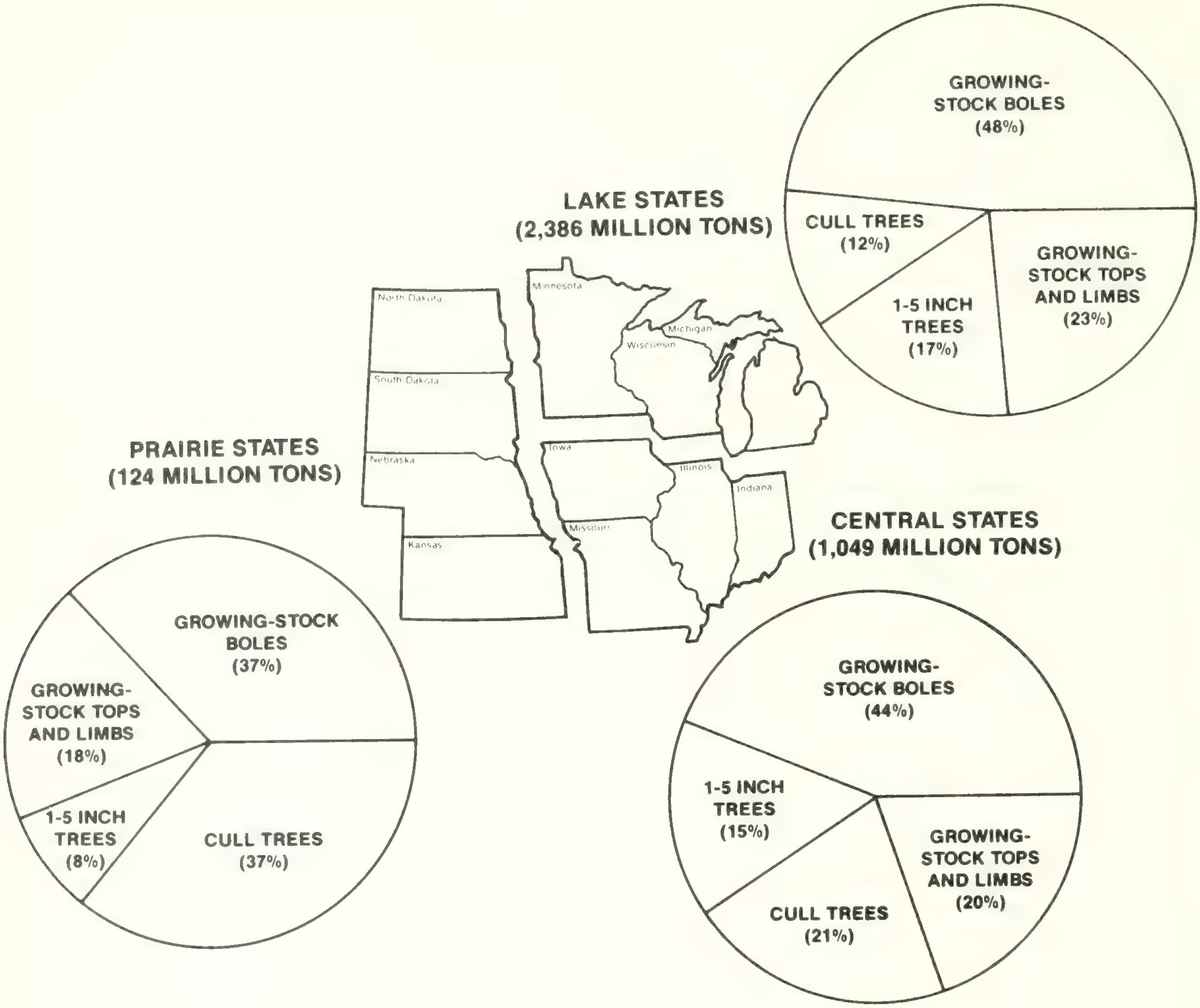

Figure 2.—*Distribution of tree biomass by biomass component and unit, North Central Region, 1978.*

Tree biomass in the Prairie States is scattered across a number of tree species with no single species accounting for a large portion of the total (table 5). The 124 million green tons found in the Unit is concentrated in hardwoods (112 million green tons). Ponderosa pine accounts for most of the softwood biomass volume.

In all units, most tree biomass is privately owned (tables 6-8). Public owners hold a larger percentage of the softwood than hardwood biomass in all units:

Ownership class	Softwood biomass	Hardwood biomass
	(Percent)	
	Central States	
Public	39	12
Private	61	88
	Lake States	
Public	47	34
Private	53	66
	Prairie States	
Public	37	6
Private	63	94

DISCUSSION

The tree biomass for each State is correlated to the tree volume, size, and species found in the State. The States with the highest growing-stock volumes per acre generally have the highest tree biomass weights per acre. Because the weight per cubic foot of wood varies widely by species group, small differences in the species composition of forests among the States can result in large differences in the total tree biomass:

Species group	Green weight of aboveground tree biomass (Pounds per cubic foot)[8]
Softwoods	
Jack pine	50
Red pine	42
Loblolly-shortleaf pine	53
White spruce	35
Black spruce	32
Balsam fir	45
Northern white-cedar	28
Other softwoods	50
Hardwoods	
White oak	62
Red oak	63
Hickory	63
Hard maple	56
Soft maple	50
Aspen-cottonwood	43
Birch	50
Other hardwoods	50

In Indiana, with the highest tree biomass per acre, red and white oaks account for 24 percent and hickory for 16 percent of the total number of growing-stock trees. Therefore, 40 percent of Indiana's trees are in the three species groups with the most dense wood. In Illinois, the species composition is similar to that found in Indiana, but the number of trees per acre of commercial forest land is so low that tree biomass per acre is the lowest in the Region.

As tree size increases linearly, weight per tree increases exponentially (fig. 3). For example, if oak diameter increases from 6 to 12 inches, the biomass per growing-stock tree increases 490 percent and the biomass per cull tree increases 590 percent. The increase in aspen and cottonwood growing-stock biomass per tree is even more dramatic. In this species group, an increase in diameter from 6 to 12 inches results in an 820 percent increase in growing-stock biomass per tree.

The RRE definitions of biomass for trees larger than 5 inches in diameter exclude a 1-foot stump. To fully calculate the aboveground biomass of a tree, the volume in the stump must be known. Raile (1981) developed a method for estimating the volume in stumps of various heights for any tree diameter. In the tabulation below, we used this method to estimate the weight of a 1-foot stump for an average softwood or hardwood growing-stock tree across a range of diameters. Stump weight is given as a percentage of the weight of the growing-stock bole:

D.b.h. (Inches)	Stump weight as a percent of the weight in the growing-stock bole	
	Softwoods	Hardwoods
6	10.2	15.8
8	9.0	12.6
10	8.2	10.7
12	7.5	9.4
14	7.0	8.5
16	6.6	7.8
18	6.3	7.2
20	6.0	6.8
22	5.8	6.5
24	5.6	6.1
26	5.4	5.9
28	5.2	5.7
30	5.1	5.5

For example, the weight of a 1-foot stump for a 6-inch d.b.h. hardwood growing-stock tree is 15.8 percent of the bole biomass.

Estimates of tree biomass can be used in conjunction with timber removals data to estimate the amount of wood left in forests after conventional logging operations. In 1976, growing-stock removals from commercial forest land in the North Central Region totaled 1,109 million cubic feet—195 million cubic feet from softwoods and 916 million cubic feet from hardwoods. Of this total, only 54 percent was used for products:

Item	1976 growing-stock removals	
	Softwoods	Hardwoods
	(Million cubic feet)	
Products	152	554
Logging residue	4	57
Other removals[9]	39	305
	195	916

The 706 million cubic feet used for products is equal to 22 million green tons. By definition growing-stock removals come only from the boles of grow-

---

[8] *Adopted from L. J. Markwardt (1930).*

[9] *Other removals are (1) growing-stock volumes removed during land clearing and timber stand improvement work but not utilized for products, and (2) volumes lost as a result of changes in land use.*

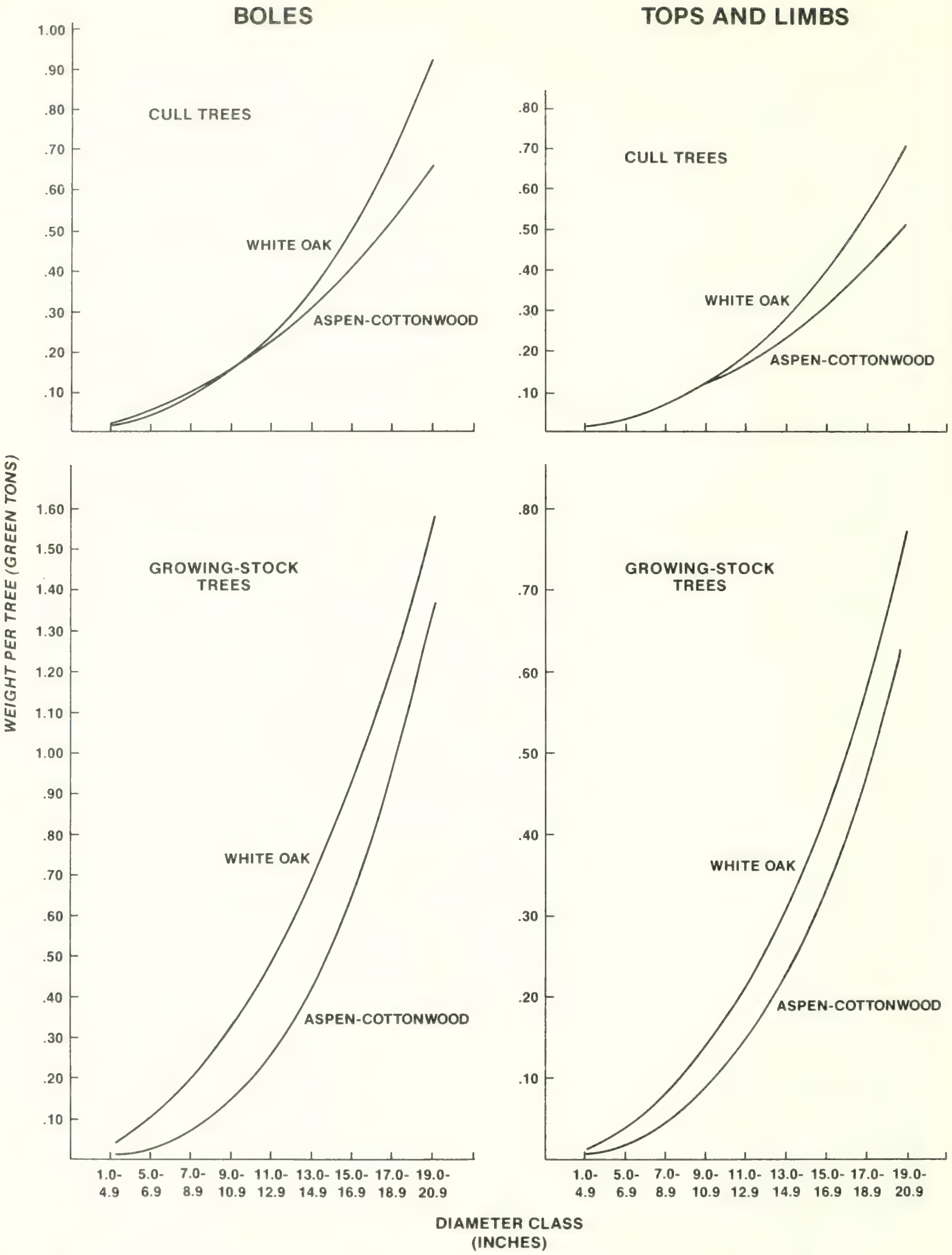

Figure 3.—*Green weight per tree by diameter class and biomass component, white oak and aspen-cottonwood, North Central Region.*

ing-stock trees, and boles account for an average of 68 percent of the total growing-stock tree biomass. This means that on the average, 32 percent of the total tree biomass is left in forests following harvest.

In the North Central Region in 1976 an estimated 10 million green tons of tops and limbs were left following removal of the growing-stock boles for products. In addition, more than 2 million green tons of logging residue were left. Logging residue is unused portions of the bole from cut growing-stock trees plus unused growing-stock trees killed by logging. Therefore, 12 million green tons of tree biomass are available for energy production or new forest products without jeopardizing current supplies.

As mentioned earlier, many opportunities exist for using tree biomass to help alleviate some of the Nation's energy problems: burning wood provides an alternative way to heat homes and buildings or generate electricity, wood-derived chemicals can be used as petroleum substitutes, and wood products can be substituted for energy-intensive metals and plastics. Current use of woody biomass for energy is about 1.3 quads,[10] or 2 percent of the Nation's energy budget. By 1990, energy from woody biomass could be 6.4 quads, or about 8 percent of the Nation's energy budget (USDA Forest Service 1980).

The amount of energy available per pound of wood is fairly consistent across species groups. Wood at 20 percent moisture content produces approximately 6,400 Btu's per pound of wood (Agricultural Extension Service 1979). However, the energy available per unit volume of wood varies because species that are more dense have more pounds of wood per unit volume. The available heat units (in million Btu's per cord of 90 solid cubic feet) of wood and bark are shown below for several north-central species (Hendricks 1974).

Species	**Air-dry**[11]	**Green**
	(Million Btu's per 90 solid cubic feet)	
Red pine	17.8	16.8
White pine	14.2	12.9
Hemlock	15.0	12.8
White oak	23.9	22.4
Red oak	21.7	19.6
Hickory	24.8	23.1
Aspen	14.1	12.2
Paper birch	18.2	16.7
Elm	17.7	15.8

The energy content of tree biomass in the North Central Region is 26.3 x 10^{15} Btu's. Hardwoods account for 80 percent of the energy potential. The energy content of the 12 million green tons of unused tops and limbs and logging residue is approximately 92.4 X 10^{12} Btu's.

SUMMARY

The estimates of tree biomass presented here are a first step toward estimating total woody biomass on commercial forest land. The next step will entail estimating woody biomass in the forest understory. Methods for calculating biomass of the major north-central shrub species are currently being refined and evaluated by Project scientists. The Project anticipates using the method described above to estimate tree biomass as part of the standard forest inventory in each State.

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[10] *One quad = 1.0 X 10^{15} British Thermal Units (Btu's).*

[11] *From 15 to 20 percent moisture.*

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Table 1.--Biomass equation parameters

	Biomass Component							
	Growing stock				Cull			
	Boles		Tops and limbs		Boles		Tops and limbs	
Species	A	B	A	B	A	B	A	B
	$\times 10^{-3}$		$\times 10^{-3}$		$\times 10^{-3}$		$\times 10^{-3}$	
Jack pine	1.959	2.1457	.453	2.4197	.646	2.2562	.720	2.2633
Red pine [1]	1.453	2.2749	1.410	2.0285	1.844	1.8345	2.083	1.8429
White pine	.539	2.5895	.132	2.8060	.077	3.0459	.059	3.0415
White spruce	.392	2.6898	.236	2.6177	.118	2.7082	.153	2.7497
Black spruce	.190	2.8971	.197	2.7108	.316	2.3167	.074	3.0300
Balsam fir	.706	2.5404	.266	2.6321	.001	4.5421	.002	4.5427
Hemlock	.337	2.7915	.225	2.6652	.093	2.9225	.099	2.9265
Tamarack	.650	2.5857	.668	2.3282	.031	3.3055	.042	3.3107
Northern white-cedar	.384	2.5461	.138	2.7198	.134	2.6150	.146	2.6229
Other softwoods	1.066	2.3170	1.336	1.8396	.184	2.7407	.148	2.7578
Select white oak	1.996	2.2276	.485	2.4591	.419	2.5684	.320	2.5687
Select red oak	1.451	2.3582	.443	2.5155	.468	2.5535	.363	2.5537
Select hickory	5.274	1.8599	1.940	1.9741	.221	2.8099	.176	2.8005
Beech	2.476	2.1046	.600	2.3265	.109	2.9984	.078	2.9991
Hard maple	.792	2.5477	.365	2.5440	.736	2.3281	.582	2.3264
Soft maple	1.072	2.3888	.459	2.4164	1.124	2.1090	.139	2.7753
Ash	.926	2.3419	.269	2.6291	.117	2.1310	.930	2.1301
Aspen-cottonwood	.119	3.1213	.110	2.9053	1.150	2.1194	.876	2.1207
Birch	4.294	1.8932	.383	2.5301	1.084	2.2015	.807	2.1970
Yellow poplar	2.424	2.1077	.609	2.3201	5.725	1.6789	.322	1.6273
Other hardwoods	1.147	2.3659	.407	2.4564	.942	2.2122	.749	2.2100

[1] Red pine parameters were used for ponderosa and loblolly-shortleaf pine species groups.

Table 2.--Total green weight of aboveground tree biomass on commercial forest land by State, softwoods and hardwoods, biomass component, and Unit

(In thousand green tons)

			Biomass component			
			Growing-stock		Cull	
State	All components	1"-5" trees	Boles	Tops and limbs	Boles	Tops and limbs
CENTRAL STATES						
Illinois						
Softwoods	2,138	509	900	486	117	126
Hardwoods	165,103	14,963	89,865	41,052	10,852	8,371
Total	167,241	15,472	90,765	41,538	10,969	8,497
Indiana						
Softwoods	4,924	1,290	2,299	1,073	145	127
Hardwoods	210,971	25,705	110,232	50,700	13,815	10,519
Total	215,895	26,995	112,531	51,773	13,960	10,646
Iowa						
Softwoods	578	147	206	91	72	62
Hardwoods	75,354	8,882	34,060	15,624	9,434	7,354
Total	75,932	9,029	34,266	15,715	9,506	7,416
Missouri						
Softwoods	25,585	5,922	11,978	6,488	578	619
Hardwoods	564,485	99,765	216,260	95,349	86,372	66,739
Total	590,070	105,687	228,238	101,837	86,950	67,358
Unit totals						
Softwoods	33,225	7,758	15,383	8,138	1,012	934
Hardwoods	1,015,913	149,415	450,417	202,725	120,373	92,983
Total	1,049,138	157,173	465,800	210,863	121,385	93,917
LAKE STATES						
Michigan						
Softwoods	252,569	55,039	125,432	61,417	5,114	5,567
Hardwoods	777,988	126,717	390,202	178,209	47,134	35,726
Total	1,030,557	181,756	515,634	239,626	52,248	41,293
Minnesota						
Softwoods	183,475	56,047	80,160	38,436	5,231	3,601
Hardwoods	477,442	79,469	222,086	108,571	38,897	28,419
Total	660,917	135,516	302,246	147,007	44,128	32,020
Wisconsin						
Softwoods	155,333	26,005	82,461	39,297	3,691	3,879
Hardwoods	538,839	69,529	256,050	115,316	55,615	42,329
Total	694,172	95,534	338,511	154,613	59,306	46,208
Unit totals						
Softwoods	591,377	137,091	288,053	139,150	14,036	13,047
Hardwoods	1,794,269	275,715	868,338	402,096	141,646	106,474
Total	2,385,646	412,806	1,156,391	541,246	155,682	119,521
PRAIRIE STATES						
Kansas						
Softwoods	90	13	15	7	31	24
Hardwoods	58,126	5,628	17,799	8,270	14,834	11,595
Total	58,216	5,641	17,814	8,277	14,865	11,619
Nebraska						
Softwoods	10,279	662	5,908	3,149	260	300
Hardwoods	28,487	616	11,835	5,707	5,819	4,510
Total	38,766	1,278	17,743	8,856	6,079	4,810
North Dakota						
Softwoods	72	6	43	19	3	1
Hardwoods	15,903	2,720	5,979	2,841	2,763	1,600
Total	15,975	2,726	6,022	2,860	2,766	1,601
South Dakota						
Softwoods	1,886	252	964	545	59	66
Hardwoods	9,637	479	3,858	1,906	1,908	1,486
Total	11,523	731	4,822	2,451	1,967	1,552
Unit totals						
Softwoods	12,327	933	6,930	3,720	353	391
Hardwoods	112,153	9,443	39,471	18,724	25,324	19,191
Total	124,480	10,376	46,401	22,444	25,677	19,582

Table 3.--Total green weight of aboveground tree biomass on commercial forest land by species group, diameter, class and biomass component, Central States

(In thousand green tons)

Species group	All components	Biomass component: Growing-stock: Boles	Growing-stock: Tops and limbs	Cull: Boles	Cull: Tops and limbs
LOBLOLLY-SHORTLEAF PINE					
1.0" - 4.9"	4,038	1,823	1,309	423	483
5.0" - 6.9"	3,875	2,196	1,371	143	165
7.0" - 8.9"	4,807	2,955	1,719	61	72
9.0" - 10.9"	4,193	2,671	1,470	24	28
11.0" - 12.9	3,145	2,037	1,072	17	19
13.0" - 14.9	1,314	855	433	12	14
15.0" - 16.9"	447	300	147	--	--
17.0" - 18.9"	251	165	78	4	4
19.0" - 20.9"	67	42	20	2	3
21.0" - 28.9	--	--	--	--	--
29.0" - over	--	--	--	--	--
Total	22,137	13,044	7,619	686	788
OTHER SOFTWOODS					
1.0" - 4.9"	3,720	1,995	1,457	147	121
5.0" - 6.9"	1,965	1,096	584	156	129
7.0" - 8.9"	1,858	1,077	501	152	128
9.0" - 10.9"	1,419	764	319	183	153
11.0" - 12.9"	891	481	184	123	103
13.0" - 14.9"	483	283	100	54	46
15.0" - 16.9"	302	178	59	35	30
17.0" - 18.9"	127	86	27	7	7
19.0" - 20.9"	75	31	10	19	15
21.0" - 28.9"	128	93	25	5	5
29.0" - over	120	73	19	15	13
Total	11,088	6,157	3,285	896	750
TOTAL SOFTWOODS					
1.0" - 4.9"	7,758	3,818	2,766	570	604
5.0" - 6.9"	5,840	3,292	1,955	299	294
7.0" - 8.9	6,665	4,032	2,220	213	200
9.0' - 10.9"	5,612	3,435	1,789	207	181
11.0" - 12.9"	4,036	2,518	1,256	140	122
13.0" - 14.9"	1,797	1,138	533	66	60
15.0" - 16.9"	749	478	206	35	30
17.0" - 18.9"	378	251	105	11	11
19.0" - 20.9"	142	73	30	21	18
21.0" - 28.9"	128	93	25	5	5
29.0" - over	120	73	19	15	13
Total	33,225	19,201	10,904	1,582	1,538
WHITE OAK					
1.0" - 4.9"	33,186	18,381	5,955	5,016	3,834
5.0" - 6.9"	33,821	19,625	7,221	3,952	3,023
7.0" - 8.9"	38,889	22,685	8,921	4,126	3,157
9.0" - 10.9"	42,520	23,383	9,684	5,356	4,097
11.0" - 12.9"	40,296	21,407	9,248	5,463	4,178
13.0" - 14.9"	39,213	20,527	9,190	5,380	4,116
15.0" - 16.9"	26,992	13,154	6,073	4,399	3,366
17.0" - 18.9"	17,279	7,870	3,734	3,215	2,460
19.0" - 20.9"	11,042	4,439	2,159	2,518	1,926
21.0" - 28.9"	16,728	5,676	2,878	4,631	3,543
29.0" - over	3,017	1,044	553	804	616
Total	302,983	158,191	65,616	44,860	34,316
RED OAK					
1.0" - 4.9"	24,384	13,277	4,914	3,488	2,705
5.0" - 6.9"	23,917	13,235	5,358	2,998	2,326
7.0" - 8.9"	31,822	17,357	7,351	4,006	3,108
9.0" - 10.9"	39,539	21,129	9,269	5,147	3,994
11.0" - 12.9"	37,678	19,600	8,848	5,197	4,033
13.0" - 14.9"	33,062	17,155	7,934	4,489	3,484
15.0" - 16.9"	27,002	13,425	6,341	4,074	3,162
17.0" - 18.9"	19,389	9,319	4,485	3,145	2,440
19.0" - 20.9"	13,994	6,269	3,066	2,623	2,036
21.0" - 28.9"	21,994	8,990	4,526	4,773	3,705
29.0" - over	3,522	1,089	565	1,052	816
Total	276,303	140,845	62,657	40,992	31,809

(Table 3 continued on next page)

(Table 3 continued)

Species group	All components	Growing-stock Boles	Growing-stock Tops and limbs	Cull Boles	Cull Tops and limbs
		Biomass component*			
HICKORY					
1.0" - 4.9"	41,200	25,712	10,794	2,627	2,067
5.0" - 6.9"	25,745	16,005	7,223	1,413	1,104
7.0" - 8.9"	22,348	13,465	6,280	1,463	1,140
9.0" - 10.9"	19,289	11,305	5,408	1,449	1,127
11.0" - 12.9"	13,684	7,720	3,772	1,234	958
13.0" - 14.9"	9,409	5,388	2,678	756	587
15.0" - 16.9"	6,161	3,442	1,737	554	428
17.0" - 18.9"	3,433	1,827	936	377	293
19.0" - 20.9"	1,647	836	433	213	165
21.0" - 28.9"	1,589	762	403	239	185
29.0" - over	150	67	35	27	21
Total	144,655	86,529	39,699	10,352	8,075
HARD MAPLE					
1.0" - 4.9"	3,470	1,826	838	450	356
5.0" - 6.9"	3,228	1,897	868	259	204
7.0" - 8.9"	3,555	2,012	921	348	274
9.0" - 10.9"	3,687	2,106	963	346	272
11.0" - 12.9"	3,068	1,707	780	325	256
13.0" - 14.9"	3,570	1,955	893	404	318
15.0" - 16.9"	2,851	1,584	723	305	239
17.0" - 18.9"	2,095	1,022	466	340	267
19.0" - 20.9"	1,321	621	283	234	183
21.0" - 28.9"	2,068	796	363	509	400
29.0" - over	222	42	20	90	70
Total	29,135	15,568	7,118	3,610	2,839
SOFT MAPLE					
1.0" - 4.9"	2,961	1,253	553	913	242
5.0" - 6.9"	2,479	1,329	597	343	210
7.0" - 8.9"	2,858	1,576	714	380	188
9.0" - 10.9"	3,065	1,722	786	354	203
11.0" - 12.9"	3,389	1,851	848	419	271
13.0" - 14.9"	3,153	1,831	843	279	200
15.0" - 16.9"	2,485	1,377	636	265	207
17.0" - 18.9"	1,697	912	424	195	166
19.0" - 20.9"	1,425	756	352	166	151
21.0" - 28.9"	3,487	1,677	783	506	521
29.0" - over	1,277	570	269	203	235
Total	28,276	14,854	6,805	4,073	2,544
ASH					
1.0" - 4.9"	5,243	1,679	688	1,604	1,272
5.0" - 6.9"	4,660	2,131	1,035	834	660
7.0" - 8.9"	4,678	2,219	1,171	719	569
9.0" - 10.9"	4,111	1,976	1,111	572	452
11.0" - 12.9"	3,583	1,733	1,028	458	364
13.0" - 14.9"	2,548	1,240	768	301	239
15.0" - 16.9"	1,868	963	619	160	126
17.0" - 18.9"	1,391	651	434	171	135
19.0" - 20.9"	843	364	250	128	101
21.0" - 28.9"	1,250	512	371	205	162
29.0" - over	146	52	40	30	24
Total	30,321	13,520	7,515	5,182	4,104
BIRCH					
1.0" - 4.9"	235	96	20	69	50
5.0" - 6.9"	424	260	72	53	39
7.0" - 8.9"	317	210	70	21	16
9.0" - 10.9"	316	199	77	23	17
11.0" - 12.9"	285	160	70	32	23
13.0" - 14.9"	439	196	94	86	63
15.0" - 16.9"	218	104	54	34	26
17.0" - 18.9"	167	70	40	33	24
19.0" - 20.9"	93	43	26	14	10
21.0" - 28.9"	167	63	43	35	26
29.0" - over	60	18	13	17	12
Total	2,721	1,419	579	417	306

(Table 3 continued on next page)

(Table 3 continued)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
		ASPEN-COTTONWOOD			
1.0" - 4.9"	581	114	80	220	167
5.0" - 6.9"	544	225	141	101	77
7.0" - 8.9"	674	317	187	96	74
9.0" - 10.9"	845	458	257	74	56
11.0" - 12.9"	1,005	568	306	74	57
13.0" - 14.9"	963	587	306	40	30
15.0" - 16.9"	963	611	308	25	19
17.0" - 18.9"	1,222	759	375	50	38
19.0" - 20.9"	1,344	819	396	73	56
21.0" - 28.9"	4,053	2,516	1,167	210	160
29.0" - over	1,163	699	312	86	66
Total	13,357	7,673	3,835	1,049	800
		BEECH			
1.0" - 4.9"	394	268	84	24	18
5.0" - 6.9"	381	234	85	36	26
7.0" - 8.9"	613	382	147	49	35
9.0" - 10.9"	620	361	146	66	47
11.0" - 12.9"	662	381	161	70	50
13.0" - 14.9"	767	497	217	31	22
15.0" - 16.9"	971	531	238	118	84
17.0" - 18.9"	1,227	573	263	228	163
19.0" - 20.9"	740	347	164	133	96
21.0" - 28.9"	2,111	567	278	737	529
29.0" - over	726	95	49	339	243
Total	9,212	4,236	1,832	1,831	1,313
		YELLOW-POPLAR			
1.0" - 4.9"	1,275	748	239	188	100
5.0" - 6.9"	962	598	220	95	49
7.0" - 8.9"	1,070	729	284	38	19
9.0" - 10.9"	1,143	772	317	36	18
11.0" - 12.9"	1,311	849	361	68	33
13.0" - 14.9"	1,451	971	428	35	17
15.0" - 16.9"	948	614	278	38	18
17.0" - 18.9"	876	543	252	55	26
19.0" - 20.9"	576	376	179	14	7
21.0" - 28.9"	828	480	237	75	36
29.0" - over	100	33	17	34	16
Total	10,540	6,713	2,812	676	339
		OTHER HARDWOODS			
1.0" - 4.9"	36,486	8,968	3,550	13,364	10,604
5.0" - 6.9"	23,008	9,563	3,988	5,277	4,180
7.0" - 8.9"	22,078	10,701	4,579	3,794	3,004
9.0" - 10.9"	19,763	10,186	4,449	2,863	2,265
11.0" - 12.9"	16,061	8,199	3,641	2,357	1,864
13.0" - 14.9"	14,036	7,301	3,287	1,925	1,523
15.0" - 16.9"	11,513	5,948	2,710	1,595	1,260
17.0" - 18.9"	7,850	3,969	1,827	1,147	907
19.0" - 20.9"	5,451	2,564	1,192	947	748
21.0" - 28.9"	9,794	4,604	2,177	1,684	1,329
29.0" - over	2,370	1,188	572	341	269
Total	168,410	73,191	31,972	35,294	27,953
		TOTAL HARDWOODS			
1.0" - 4.9"	149,415	72,322	27,715	27,963	21,415
5.0" - 6.9"	119,169	65,102	26,808	15,411	11,848
7.0" - 8.9"	128,902	71,653	30,625	15,040	11,584
9.0" - 10.9"	134,898	73,597	32,467	16,286	12,548
11.0" - 12.9"	121,022	64,175	29,063	15,697	12,087
13.0" - 14.9"	108,611	57,648	26,638	13,726	10,599
15.0" - 16.9"	81,972	41,753	19,717	11,567	8,935
17.0" - 18.9"	56,626	27,515	13,236	8,956	6,919
19.0" - 20.9"	38,476	17,434	8,500	7,063	5,479
21.0" - 28.9"	64,069	26,643	13,226	13,604	10,596
29.0" - over	12,753	4,897	2,445	3,023	2,388
Total	1,015,913	522,739	230,440	148,336	114,398
All species	1,049,138	541,940	241,344	149,918	115,936

Table 4.--Total green weight of aboveground tree biomass on commercial forest land by species group, diameter class, and biomass component, Lake States

(In thousand green tons)

Species group	All components	Growing-stock Boles	Growing-stock Tops and limbs	Cull Boles	Cull Tops and limbs
			JACK PINE		
1.0" - 4.9"	24,570	17,016	5,711	983	860
5.0" - 6.9"	26,286	17,781	7,076	698	731
7.0" - 8.9"	25,683	17,010	7,218	[illegible]	[illegible]
9.0" - 10.9"	15,625	9,931	4,394	[illegible]	[illegible]
11.0" - 12.9"	7,611	4,864	2,211	[illegible]	[illegible]
13.0" - 14.9"	3,083	1,894	881	159	149
15.0" - 16.9"	1,043	614	292	77	60
17.0" - 18.9"	302	152	75	47	28
19.0" - 20.9"	55	21	11	13	10
21.0" - 28.9"	34	23	11	—	—
29.0" - over	--	--	--	--	--
Total	104,292	69,306	27,880	3,648	3,458
			RED PINE		
1.0" - 4.9"	13,444	7,604	5,280	271	289
5.0" - 6.9"	11,531	6,914	4,225	190	202
7.0" - 8.9"	8,544	5,319	2,978	123	124
9.0" - 10.9"	6,285	3,950	2,049	144	142
11.0" - 12.9"	5,924	3,793	1,917	102	112
13.0" - 14.9"	6,109	3,963	1,962	88	96
15.0" - 16.9"	5,365	3,542	1,718	48	57
17.0" - 18.9"	4,326	2,877	1,366	40	43
19.0" - 20.9"	2,307	1,538	716	26	27
21.0" - 28.9"	2,311	1,574	704	16	17
29.0" - over	15	9	4	1	1
Total	66,161	41,083	22,919	1,049	1,110
			WHITE PINE		
1.0" - 4.9"	1,851	1,260	425	108	58
5.0" - 6.9"	2,002	1,350	501	92	59
7.0" - 8.9"	2,829	1,852	727	146	104
9.0" - 10.9"	4,033	2,661	1,090	165	117
11.0" - 12.9"	5,422	3,518	1,496	238	170
13.0" - 14.9"	5,652	3,711	1,625	182	134
15.0" - 16.9"	5,733	3,699	1,663	213	158
17.0" - 18.9"	5,428	3,488	1,605	192	143
19.0" - 20.9"	4,126	2,643	1,244	136	103
21.0" - 28.9"	7,803	4,738	2,334	415	316
29.0" - over	1,201	730	378	52	41
Total	46,080	29,650	13,088	1,939	1,403
			WHITE SPRUCE		
1.0" - 4.9"	3,718	2,347	1,206	100	65
5.0" - 6.9"	3,337	2,119	1,120	48	50
7.0" - 8.9"	4,272	2,733	1,404	62	73
9.0" - 10.9"	3,647	2,305	1,159	79	104
11.0" - 12.9"	2,891	1,844	912	59	76
13.0" - 14.9"	2,183	1,401	689	38	55
15.0" - 16.9"	1,466	953	463	21	29
17.0" - 18.9"	704	454	220	13	17
19.0" - 20.9"	418	274	132	5	7
21.0" - 28.9"	370	241	116	5	8
29.0" - over	--	--	--	--	--
Total	23,006	14,671	7,421	430	484
			BLACK SPRUCE		
1.0" - 4.9"	23,568	13,969	7,262	1,596	741
5.0" - 6.9"	13,309	8,176	4,632	289	212
7.0" - 8.9"	8,636	5,325	2,986	179	146
9.0" - 10.9"	3,404	2,059	1,154	103	88
11.0" - 12.9"	1,032	620	345	35	32
13.0" - 14.9"	422	249	141	17	15
15.0" - 16.9"	244	149	85	7	3
17.0" - 18.9"	113	68	39	2	4
19.0" - 20.9"	19	12	7	--	—
21.0" - 28.9"	2	1	1	—	—
29.0" - over	3	--	--	1	2
Total	50,757	30,628	16,652	2,229	1,248

(Table 4 continued on next page)

(Table 4 continued)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
BALSAM FIR					
1.0" - 4.9"	42,799	28,353	12,367	1,418	661
5.0" - 6.9"	36,204	24,302	11,056	533	313
7.0" - 8.9"	29,788	19,945	9,171	382	290
9.0" - 10.9"	16,720	10,936	5,097	355	332
11.0" - 12.9"	6,971	4,506	2,139	162	164
13.0" - 14.9"	2,294	1,462	701	64	67
15.0" - 16.9"	802	500	243	28	31
17.0" - 18.9"	290	153	73	28	36
19.0" - 20.9"	53	32	16	2	3
21.0" - 28.9"	10	7	3	--	--
29.0" - over	--	--	--	--	--
Total	135,931	90,196	40,866	2,972	1,897
HEMLOCK					
1.0" - 4.9"	1,519	934	535	24	26
5.0" - 6.9"	1,950	1,214	647	43	46
7.0" - 8.9"	3,948	2,456	1,264	110	118
9.0" - 10.9"	6,871	4,189	2,096	282	304
11.0" - 12.9"	8,089	5,013	2,452	300	324
13.0" - 14.9"	8,274	5,212	2,499	271	292
15.0" - 16.9"	7,338	4,643	2,190	243	262
17.0" - 18.9"	5,125	3,256	1,512	172	185
19.0" - 20.9"	3,803	2,449	1,122	112	120
21.0" - 28.9"	6,667	4,261	1,909	239	258
29.0" - over	397	256	112	14	15
Total	53,981	33,883	16,338	1,810	1,950
TAMARACK					
1.0" - 4.9"	8,808	5,040	2,928	566	274
5.0" - 6.9"	8,572	5,019	2,972	334	247
7.0" - 8.9"	6,606	3,973	2,219	231	183
9.0" - 10.9"	3,203	1,924	1,020	135	124
11.0" - 12.9"	1,617	969	498	76	74
13.0" - 14.9"	648	376	191	39	42
15.0" - 16.9"	246	149	75	11	11
17.0" - 18.9"	127	72	35	11	9
19.0" - 20.9"	22	12	6	2	2
21.0" - 28.9"	3	2	1	--	--
29.0" - over	--	--	--	--	--
Total	29,852	17,536	9,945	1,405	966
NORTHERN WHITE-CEDAR					
1.0" - 4.9"	16,380	10,370	4,636	860	514
5.0" - 6.9"	14,453	8,931	4,425	563	534
7.0" - 8.9"	16,206	9,755	5,005	739	707
9.0" - 10.9"	13,480	7,681	4,051	892	856
11.0" - 12.9"	8,197	4,545	2,461	607	584
13.0" - 14.9"	5,024	2,797	1,551	339	337
15.0" - 16.9"	2,811	1,541	877	197	196
17.0" - 18.9"	1,564	859	501	98	106
19.0" - 20.9"	893	488	290	55	60
21.0" - 28.9"	1,252	686	428	64	74
29.0" - over	42	22	15	2	3
Total	80,302	47,675	24,240	4,416	3,971
OTHER SOFTWOODS					
1.0" - 4.9"	434	214	127	61	32
5.0" - 6.9"	173	96	50	14	13
7.0" - 8.9"	174	100	48	14	12
9.0" - 10.9"	84	48	22	9	5
11.0" - 12.9"	114	69	28	9	8
13.0" - 14.9"	15	3	2	6	4
15.0" - 16.9"	9	2	1	4	2
17.0" - 18.9"	3	--	--	2	1
19.0" - 20.9"	6	--	--	4	2
21.0" - 28.9"	3	--	--	2	1
29.0" - over	--	--	--	--	--
Total	1,015	532	278	125	80

(Table 4 continued on next page)

(Table 4 continued)

TOTAL SOFTWOODS					
		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
1.0" - 4.9"	137,091	87,107	40,477	5,987	3,520
5.0" - 6.9"	117,817	75,902	36,704	2,804	2,407
7.0" - 8.9"	106,686	68,468	33,020	2,714	2,484
9.0" - 10.9"	73,352	45,684	22,132	2,825	2,711
11.0" - 12.9"	47,868	29,741	14,459	1,870	1,798
13.0" - 14.9"	33,704	21,068	10,242	1,203	1,191
15.0" - 16.9"	25,062	15,792	7,607	849	814
17.0" - 18.9"	17,982	11,379	5,426	605	572
19.0" - 20.9"	11,702	7,469	3,544	355	334
21.0" - 28.9"	18,455	11,533	5,507	741	674
29.0" - over	1,658	1,017	509	70	62
Total	591,377	375,160	179,627	20,023	16,567
WHITE OAK					
1.0" - 4.9"	11,425	7,225	2,561	1,007	632
5.0" - 6.9"	11,326	7,126	2,765	817	618
7.0" - 8.9"	13,591	8,272	3,365	1,119	835
9.0" - 10.9"	13,436	7,859	3,344	1,281	952
11.0" - 12.9"	13,691	7,524	3,326	1,637	1,204
13.0" - 14.9"	12,805	6,750	3,082	1,705	1,268
15.0" - 16.9"	9,835	4,984	2,352	1,435	1,064
17.0" - 18.9"	6,607	3,125	1,521	1,121	840
19.0" - 20.9"	4,551	1,974	990	905	682
21.0" - 28.9"	7,237	2,731	1,421	1,764	1,321
29.0" - over	1,323	431	232	370	290
Total	105,827	58,001	24,959	13,161	9,706
RED OAK					
1.0" - 4.9"	17,520	10,668	4,015	1,640	1,197
5.0" - 6.9"	23,937	14,305	5,849	2,134	1,649
7.0" - 8.9"	33,273	19,975	8,533	2,695	2,070
9.0" - 10.9"	36,093	21,336	9,416	3,025	2,316
11.0" - 12.9"	31,849	17,926	8,152	3,272	2,499
13.0" - 14.9"	30,058	16,681	7,779	3,166	2,432
15.0" - 16.9"	22,983	12,486	5,961	2,560	1,976
17.0" - 18.9"	15,589	8,047	3,931	2,037	1,574
19.0" - 20.9"	12,543	6,172	3,058	1,860	1,453
21.0" - 28.9"	18,990	8,525	4,357	3,425	2,683
29.0" - over	1,954	740	394	451	369
Total	244,789	136,861	61,445	26,265	20,218
HICKORY					
1.0" - 4.9"	3,519	2,347	988	108	76
5.0" - 6.9"	2,980	1,956	879	81	64
7.0" - 8.9"	2,950	1,892	878	101	79
9.0" - 10.9"	3,538	2,158	1,028	198	154
11.0" - 12.9"	1,878	1,119	541	123	95
13.0" - 14.9"	1,584	895	441	140	108
15.0" - 16.9"	878	464	232	102	80
17.0" - 18.9"	228	126	64	21	17
19.0" - 20.9"	352	166	85	57	44
21.0" - 28.9"	245	99	52	53	41
29.0" - over	--	--	--	--	--
Total	18,152	11,222	5,188	984	758
HARD MAPLE					
1.0" - 4.9"	42,371	24,333	11,159	3,982	2,897
5.0" - 6.9"	37,894	22,837	10,541	2,516	2,000
7.0" - 8.9"	32,053	19,315	8,880	2,167	1,691
9.0" - 10.9"	29,048	17,359	7,964	2,104	1,621
11.0" - 12.9"	24,992	14,273	6,546	2,358	1,815
13.0" - 14.9"	24,777	14,162	6,489	2,331	1,795
15.0" - 16.9"	20,501	11,688	5,356	1,947	1,510
17.0" - 18.9"	16,043	9,078	4,158	1,585	1,222
19.0" - 20.9"	10,225	5,016	2,295	1,634	1,280
21.0" - 28.9"	13,075	6,542	2,994	1,981	1,558
29.0" - over	864	391	178	165	130
Total	251,843	144,994	66,560	22,770	17,519

(Table 4 continued on next page)

(Table 4 continued)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
		SOFT MAPLE			
1.0" - 4.9"	35,458	20,424	9,074	4,585	1,375
5.0" - 6.9"	27,822	16,824	7,718	2,223	1,057
7.0" - 8.9"	23,561	14,092	6,449	1,961	1,059
9.0" - 10.9"	18,967	11,378	5,210	1,492	887
11.0" - 12.9"	13,571	7,905	3,633	1,224	809
13.0" - 14.9"	11,647	6,737	3,108	1,045	757
15.0" - 16.9"	6,702	3,706	1,718	720	558
17.0" - 18.9"	4,600	2,473	1,149	534	444
19.0" - 20.9"	3,086	1,488	694	477	427
21.0" - 28.9"	4,312	2,066	969	640	637
29.0" - over	1,060	407	194	228	231
Total	150,786	87,500	39,916	15,129	8,241
		ASH			
1.0" - 4.9"	19,283	10,918	4,707	2,204	1,454
5.0" - 6.9"	16,600	9,702	4,860	1,138	900
7.0" - 8.9"	17,094	10,106	5,256	971	761
9.0" - 10.9"	13,215	7,658	4,114	817	626
11.0" - 12.9"	9,110	5,050	2,827	706	527
13.0" - 14.9"	5,854	3,174	1,858	464	358
15.0" - 16.9"	3,627	1,934	1,161	301	231
17.0" - 18.9"	1,525	782	498	135	110
19.0" - 20.9"	801	384	243	95	79
21.0" - 28.9"	1,297	566	401	180	150
29.0" - over	92	33	23	17	19
Total	88,498	50,307	25,948	7,028	5,215
		BIRCH			
1.0" - 4.9"	54,135	38,483	9,597	3,728	2,327
5.0" - 6.9"	55,162	37,322	12,435	3,171	2,234
7.0" - 8.9"	50,175	32,549	12,411	3,132	2,083
9.0" - 10.9"	34,499	21,696	8,979	2,306	1,518
11.0" - 12.9"	20,101	11,586	5,153	1,993	1,369
13.0" - 14.9"	10,170	5,339	2,549	1,327	955
15.0" - 16.9"	6,618	3,440	1,765	817	596
17.0" - 18.9"	4,013	1,942	1,075	569	427
19.0" - 20.9"	3,079	1,169	693	695	522
21.0" - 28.9"	4,248	1,455	974	1,040	779
29.0" - over	627	202	154	157	114
Total	242,827	155,183	55,785	18,935	12,924
		ASPEN-COTTONWOOD			
1.0" - 4.9"	51,803	24,473	13,176	8,767	5,387
5.0" - 6.9"	56,571	29,400	16,775	5,846	4,550
7.0" - 8.9"	75,110	40,980	21,846	7,066	5,218
9.0" - 10.9"	70,684	39,044	20,038	6,718	4,884
11.0" - 12.9"	54,810	29,917	15,172	5,613	4,108
13.0" - 14.9"	32,399	17,235	8,673	3,697	2,794
15.0" - 16.9"	14,953	7,589	3,804	2,005	1,555
17.0" - 18.9"	6,272	2,682	1,503	1,140	947
19.0" - 20.9"	3,206	1,396	664	621	525
21.0" - 28.9"	2,615	1,320	499	431	365
29.0" - over	258	149	66	23	20
Total	368,681	194,185	102,216	41,927	30,353
		BEECH			
1.0" - 4.9"	3,316	2,463	777	44	32
5.0" - 6.9"	2,785	1,971	711	60	43
7.0" - 8.9"	2,658	1,838	707	66	47
9.0" - 10.9"	3,122	2,113	854	90	65
11.0" - 12.9"	3,755	2,353	991	239	172
13.0" - 14.9"	3,557	2,151	937	273	196
15.0" - 16.9"	4,030	2,367	1,062	350	251
17.0" - 18.9"	3,086	1,725	794	330	237
19.0" - 20.9"	1,936	828	390	418	300
21.0" - 28.9"	2,472	1,055	519	523	375
29.0" - over	23	9	5	5	4
Total	30,740	18,873	7,747	2,398	1,722

(Table 4 continued on next page)

(Table 4 continued)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
		YELLOW-POPLAR			
1.0" - 4.9"	53	32	10	7	4
5.0" - 6.9"	42	26	10	4	2
7.0" - 8.9"	29	19	7	2	1
9.0" - 10.9"	30	19	8	2	1
11.0" - 12.9"	30	18	8	3	1
13.0" - 14.9"	25	15	7	2	1
15.0" - 16.9"	76	44	20	8	4
17.0" - 18.9"	24	14	6	3	1
19.0" - 20.9"	--	--	--	--	--
21.0" - 28.9"	126	61	30	24	11
29.0" - over	--	--	--	--	--
Total	435	248	106	55	26
		OTHER HARDWOODS			
1.0" - 4.9"	36,832	16,234	6,641	8,355	5,602
5.0" - 6.9"	30,196	17,497	7,636	2,813	2,250
7.0" - 8.9"	57,629	36,394	15,882	2,982	2,371
9.0" - 10.9"	51,282	32,641	14,451	2,344	1,846
11.0" - 12.9"	30,052	17,791	8,016	2,359	1,886
13.0" - 14.9"	26,673	15,642	7,111	2,182	1,738
15.0" - 16.9"	18,668	10,901	5,014	1,519	1,234
17.0" - 18.9"	12,889	7,382	3,433	1,151	923
19.0" - 20.9"	8,663	4,642	2,183	1,023	815
21.0" - 28.9"	15,268	7,835	3,752	2,053	1,628
29.0" - over	3,539	1,605	812	640	482
Total	291,691	168,564	74,931	27,421	20,775
		TOTAL HARDWOODS			
1.0" - 4.9"	275,715	157,600	62,705	34,427	20,983
5.0" - 6.9"	265,315	158,966	70,179	20,803	15,367
7.0" - 8.9"	308,123	185,432	84,214	22,262	16,215
9.0" - 10.9"	273,914	163,261	75,406	20,377	14,870
11.0" - 12.9"	203,839	115,462	54,365	19,527	14,485
13.0" - 14.9"	159,549	88,781	42,034	16,332	12,402
15.0" - 16.9"	108,871	59,603	28,445	11,764	9,059
17.0" - 18.9"	70,876	37,376	18,132	8,626	6,742
19.0" - 20.9"	48,442	23,235	11,295	7,785	6,127
21.0" - 28.9"	69,885	32,255	15,968	12,114	9,548
29.0" - over	9,740	3,967	2,058	2,056	1,659
Total	1,794,269	1,025,938	464,801	176,073	127,457
All species	2,385,646	1,401,098	644,428	196,096	144,024

Table 5.--Total green weight of aboveground tree biomass on commercial forest land by species group, diameter, class and biomass component, Prairie States

(In thousand green tons)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
JACK PINE					
1.0" - 4.9"	4	3	1	--	--
5.0" - 6.9"	37	27	10	--	--
7.0" - 8.9"	59	40	17	1	1
9.0" - 10.9"	17	12	5	--	--
11.0" - 12.9"	--	--	--	--	--
13.0" - 14.9"	--	--	--	--	--
15.0" - 16.9"	--	--	--	--	--
17.0" - 18.9"	--	--	--	--	--
19.0" - 20.9"	--	--	--	--	--
21.0" - 28.9"	--	--	--	--	--
29.0" - over	--	--	--	--	--
Total	117	82	33	1	1
PONDEROSA PINE					
1.0" - 4.9"	893	390	275	107	121
5.0" - 6.9"	1,285	760	471	25	29
7.0" - 8.9"	1,900	1,142	662	46	50
9.0" - 10.9"	2,178	1,353	744	38	43
11.0" - 12.9"	2,032	1,279	673	37	43
13.0" - 14.9"	1,778	1,038	526	99	115
15.0" - 16.9"	924	570	279	35	40
17.0" - 18.9"	468	265	126	36	41
19.0" - 20.9"	245	167	78	--	--
21.0" - 28.9"	72	50	22	--	--
29.0" - over	--	--	--	--	--
Total	11,775	7,014	3,856	423	482
OTHER SOFTWOODS					
1.0" - 4.9"	36	16	11	5	4
5.0" - 6.9"	164	100	53	6	5
7.0" - 8.9"	85	47	22	9	7
9.0" - 10.9"	59	38	16	3	2
11.0" - 12.9"	48	29	11	4	4
13.0" - 14.9"	16	8	3	3	2
15.0" - 16.9"	9	5	2	1	1
17.0" - 18.9"	1	--	--	1	--
19.0" - 20.9"	2	--	--	1	1
21.0" - 28.9"	8	--	--	4	4
29.0" - over	7	--	--	4	3
Total	435	243	118	41	33
TOTAL SOFTWOODS					
1.0" - 4.9"	933	409	287	112	125
5.0" - 6.9"	1,486	887	534	31	34
7.0" - 8.9"	2,044	1,229	701	56	58
9.0" - 10.9"	2,254	1,403	765	41	45
11.0" - 12.9"	2,080	1,308	684	41	47
13.0" - 14.9"	1,794	1,046	529	102	117
15.0" - 16.9"	933	575	281	36	41
17.0" - 18.9"	469	265	126	37	41
19.0" - 20.9"	247	167	78	1	1
21.0" - 28.9"	80	50	22	4	4
29.0" - over	7	--	--	4	3
Total	12,327	7,339	4,007	465	516
WHITE OAK					
1.0" - 4.9"	1,414	552	218	385	259
5.0" - 6.9"	1,598	666	255	397	280
7.0" - 8.9"	2,105	889	367	494	355
9.0" - 10.9"	2,141	883	383	511	364
11.0" - 12.9"	1,949	849	372	423	305
13.0" - 14.9"	1,672	682	309	391	290
15.0" - 16.9"	1,169	479	223	268	199
17.0" - 18.9"	1,079	439	208	247	185
19.0" - 20.9"	907	364	176	209	158
21.0" - 28.9"	1,753	437	221	621	474
29.0" - over	405	58	31	179	137
Total	16,192	6,298	2,763	4,125	3,006

(Table 5 continued on next page)

(Table 5 continued)

Species group	All components	Growing-stock Boles	Growing-stock Tops and limbs	Cull Boles	Cull Tops and limbs
		RED OAK			
1.0" - 4.9"	319	126	47	82	64
5.0" - 6.9"	445	208	84	86	67
7.0" - 8.9"	523	255	108	90	70
9.0" - 10.9"	501	222	97	102	80
11.0" - 12.9"	615	334	151	73	57
13.0" - 14.9"	620	325	150	81	64
15.0" - 16.9"	556	276	131	84	65
17.0" - 18.9"	480	231	111	78	60
19.0" - 20.9"	403	195	96	63	49
21.0" - 28.9"	588	201	101	161	125
29.0" - over	77	--	--	43	34
Total	5,127	2,373	1,076	943	735
		HICKORY			
1.0" - 4.9"	297	175	74	27	21
5.0" - 6.9"	483	295	133	31	24
7.0" - 8.9"	484	282	131	[illegible]	[illegible]
9.0" - 10.9"	362	187	90	[illegible]	[illegible]
11.0" - 12.9"	284	142	69	41	32
13.0" - 14.9"	194	91	45	33	25
15.0" - 16.9"	205	103	52	28	22
17.0" - 18.9"	122	50	26	[illegible]	[illegible]
19.0" - 20.9"	155	54	28	41	32
21.0" - 28.9"	234	54	29	85	66
29.0" - over	41	--	--	23	18
Total	2,861	1,433	677	423	328
		HARD MAPLE			
1.0" - 4.9"	20	8	3	5	4
5.0" - 6.9"	41	20	9	7	5
7.0" - 8.9"	47	27	12	4	4
9.0" - 10.9"	39	17	8	8	6
11.0" - 12.9"	25	13	6	3	3
13.0" - 14.9"	40	24	11	3	2
15.0" - 16.9"	26	15	7	2	2
17.0" - 18.9"	3	--	--	2	1
19.0" - 20.9"	3	--	--	2	1
21.0" - 28.9"	15	3	1	6	5
29.0" - over	3	--	--	2	1
Total	262	127	57	44	34
		SOFT MAPLE			
1.0" - 4.9"	94	14	7	57	16
5.0" - 6.9"	74	8	4	44	18
7.0" - 8.9"	109	29	13	45	22
9.0" - 10.9"	147	51	23	46	27
11.0" - 12.9"	119	46	21	32	20
13.0" - 14.9"	118	47	22	24	25
15.0" - 16.9"	76	27	13	25	11
17.0" - 18.9"	150	69	32	27	22
19.0" - 20.9"	76	33	15	15	13
21.0" - 28.9"	162	47	22	46	47
29.0" - over	24	--	--	11	13
Total	1,149	371	172	372	234
		ASH			
1.0" - 4.9"	1,242	424	187	379	252
5.0" - 6.9"	1,384	548	263	[illegible]	[illegible]
7.0" - 8.9"	1,429	518	265	376	270
9.0" - 10.9"	1,650	595	322	[illegible]	[illegible]
11.0" - 12.9"	1,489	599	337	[illegible]	[illegible]
13.0" - 14.9"	1,592	579	343	[illegible]	[illegible]
15.0" - 16.9"	1,176	441	275	[illegible]	[illegible]
17.0" - 18.9"	705	260	163	158	124
19.0" - 20.9"	455	172	108	98	77
21.0" - 28.9"	582	123	85	210	164
29.0" - over	114	14	11	50	39
Total	11,818	4,273	2,359	2,979	2,207

(Table 5 continued on next page)

(Table 5 continued)

		Biomass component			
		Growing-stock		Cull	
Species group	All components	Boles	Tops and limbs	Boles	Tops and limbs
		BIRCH			
1.0" - 4.9"	48	31	14	2	1
5.0" - 6.9"	89	54	26	6	3
7.0" - 8.9"	85	43	20	15	7
9.0" - 10.9"	45	26	12	4	3
11.0" - 12.9"	52	35	17	--	--
13.0" - 14.9"	32	12	6	9	5
15.0" - 16.9"	--	--	--	--	--
17.0" - 18.9"	--	--	--	--	--
19.0" - 20.9"	--	--	--	--	--
21.0" - 28.9"	--	--	--	--	--
29.0" - over	--	--	--	--	--
Total	351	201	95	36	19
		ASPEN-COTTONWOOD			
1.0" - 4.9"	1,800	738	357	420	285
5.0" - 6.9"	1,821	744	385	403	289
7.0" - 8.9"	2,455	1,008	518	533	396
9.0" - 10.9"	2,590	1,046	536	575	433
11.0" - 12.9"	2,424	968	508	543	405
13.0" - 14.9"	2,265	876	452	530	407
15.0" - 16.9"	1,828	770	391	378	289
17.0" - 18.9"	1,857	793	390	385	289
19.0" - 20.9"	1,978	987	477	291	223
21.0" - 28.9"	6,419	3,242	1,511	946	720
29.0" - over	2,230	993	448	454	335
Total	27,667	12,165	5,973	5,458	4,071
		OTHER HARDWOODS			
1.0" - 4.9"	4,209	847	345	1,706	1,311
5.0" - 6.9"	4,172	1,183	496	1,402	1,091
7.0" - 8.9"	4,964	1,560	671	1,546	1,187
9.0" - 10.9"	5,081	1,590	701	1,576	1,214
11.0" - 12.9"	5,056	1,867	835	1,340	1,014
13.0" - 14.9"	5,084	1,902	862	1,316	1,004
15.0" - 16.9"	4,448	1,739	801	1,082	826
17.0" - 18.9"	3,625	1,367	634	918	706
19.0" - 20.9"	2,773	1,079	506	670	518
21.0" - 28.9"	6,114	1,826	865	1,932	1,491
29.0" - over	1,200	185	88	519	408
Total	46,726	15,145	6,804	14,007	10,770
		TOTAL HARDWOODS			
1.0" - 4.9"	9,443	2,915	1,252	3,063	2,213
5.0" - 6.9"	10,107	3,726	1,655	2,703	2,023
7.0" - 8.9"	12,201	4,611	2,105	3,143	2,342
9.0" - 10.9"	12,556	4,617	2,172	3,293	2,474
11.0" - 12.9"	12,013	4,853	2,316	2,774	2,070
13.0" - 14.9"	11,617	4,538	2,200	2,772	2,107
15.0" - 16.9"	9,484	3,850	1,893	2,121	1,620
17.0" - 18.9"	8,021	3,209	1,564	1,841	1,407
19.0" - 20.9"	6,750	2,884	1,406	1,389	1,071
21.0" - 28.9"	15,867	5,933	2,835	4,007	3,092
29.0" - over	4,094	1,250	578	1,281	985
Total	112,153	42,386	19,976	28,387	21,404
All species	124,480	49,725	23,983	28,852	21,920

Table 6.--Total green weight of aboveground tree biomass on commercial forest land by ownership class, softwoods and hardwoods, and biomass component, Central States

(In thousand green tons)

		Biomass component				
			Growing-stock		Cull	
Ownership class	All components	1"-5" trees	Boles	Tops and limbs	Boles	Tops and limbs
National Forest						
Softwoods	11,368	755	6,386	3,431	410	386
Hardwoods	83,204	13,408	34,445	15,344	11,285	8,722
Total	94,572	14,163	40,831	18,775	11,695	9,108
Other public						
Softwoods	1,741	256	919	458	57	51
Hardwoods	40,941	5,258	18,980	8,607	4,568	3,528
Total	42,682	5,514	19,899	9,065	4,625	3,579
Forest Industry						
Softwoods	1,479	268	727	392	47	45
Hardwoods	18,988	4,710	6,877	3,056	2,450	1,895
Total	20,467	4,978	7,604	3,448	2,497	1,940
Other private						
Softwoods	18,637	6,479	7,351	3,857	498	452
Hardwoods	872,780	126,039	390,115	175,718	102,070	78,838
Total	891,417	132,518	397,466	179,575	102,568	79,290
All owners						
Softwoods	33,225	7,758	15,383	8,138	1,012	934
Hardwoods	1,015,913	149,415	450,417	202,725	120,373	92,983
Total	1,049,138	157,173	465,800	210,863	121,385	93,917

Table 7.--Total green weight of aboveground tree biomass on commercial forest land by ownership class, softwoods and hardwoods, and biomass component, Lake States

(In thousand green tons)

		Biomass component				
			Growing-stock		Cull	
Ownership class	All components	1"-5" trees	Boles	Tops and limbs	Boles	Tops and limbs
National Forest						
Softwoods	94,914	15,878	50,623	24,293	2,112	2,008
Hardwoods	172,943	26,436	84,361	38,522	13,666	9,958
Total	267,857	42,314	134,984	62,815	15,778	11,966
Other public						
Softwoods	184,824	49,653	85,040	41,087	4,900	4,144
Hardwoods	433,618	69,430	207,647	97,316	33,840	25,385
Total	618,442	119,083	292,687	138,403	38,740	29,529
Forest Industry						
Softwoods	82,997	15,340	42,949	20,787	1,963	1,958
Hardwoods	172,963	24,176	85,748	39,288	13,525	10,226
Total	255,960	39,516	128,697	60,075	15,488	12,184
Other private						
Softwoods	228,642	56,220	109,441	52,983	5,061	4,937
Hardwoods	1,014,745	155,673	490,582	226,970	80,615	60,905
Total	1,243,387	211,893	600,023	279,953	85,676	65,842
All owners						
Softwoods	591,377	137,091	288,053	139,150	14,036	13,047
Hardwoods	1,794,269	275,715	868,338	402,096	141,646	106,474
Total	2,385,646	412,806	1,156,391	541,246	155,682	119,521

Table 8.--Total green weight of aboveground tree biomass on commercial forest land by ownership class, softwoods and hardwoods, and biomass component, Prairie States

(In thousand green tons)

		Biomass component				
			Growing-stock		Cull	
Ownership class	All components	1"-5" trees	Boles	Tops and limbs	Boles	Tops and limbs
National Forest						
Softwoods	2,449	65	1,465	780	65	74
Hardwoods	164	107	20	9	19	9
Total	2,613	172	1,485	789	84	83
Other public						
Softwoods	2,128	139	1,185	660	68	76
Hardwoods	6,244	509	2,338	1,116	1,286	995
Total	8,372	648	3,523	1,776	1,354	1,071
Forest Industry						
Softwoods	--	--	--	--	--	--
Hardwoods	--	--	--	--	--	--
Total	--	--	--	--	--	--
Other private						
Softwoods	7,750	729	4,280	2,280	220	241
Hardwoods	105,745	8,827	37,113	17,599	24,019	18,187
Total	113,495	9,556	41,393	19,879	24,239	18,428
All owners						
Softwoods	12,327	933	6,930	3,720	353	391
Hardwoods	112,153	9,443	39,471	18,724	25,324	19,191
Total	124,480	10,376	46,401	22,444	25,677	19,582

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Raile, Gerhard K.; Jakes, Pamela J.
Tree biomass in the North Central Region. Res. Pap. NC-220. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 22 p.

Methods for calculating tree biomass are outlined, and the biomass on commercial forest land is estimated for 11 north-central States. Tree biomass in the North Central Region totals 3.6 billion tons, or 50 tons per commercial forest acre. For all species, total tree biomass is concentrated in growing-stock boles.

KEY WORDS: tree weight, tops and limbs, energy.

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-221**

A Program and Documentation for
Simulation of Grapple Skidders and a Whole-Tree Chipper

Sharon A. Winsauer

CLEMSON UNIVERSITY
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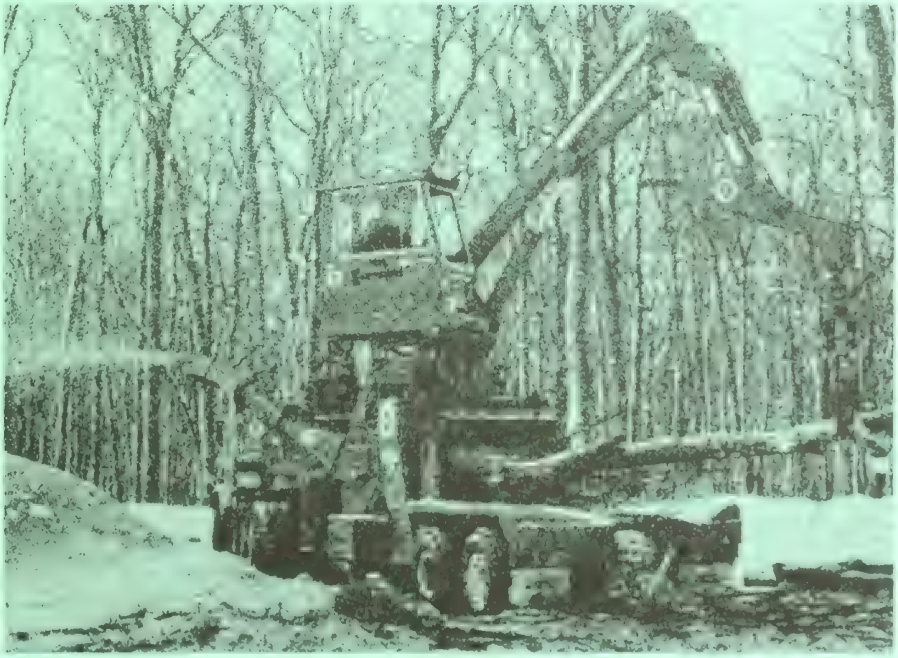

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A PROGRAM AND DOCUMENTATION FOR SIMULATION OF GRAPPLE SKIDDERS AND A WHOLE-TREE CHIPPER

Sharon A. Winsauer, *Computer Specialist,*
Houghton, Michigan

Computer simulation of forest harvesting systems is an efficient tool for resource management. The purpose of this paper is to document a computer model of a skidder-chipper system. The model was developed to provide a detailed study of the interaction between the skidders and the chipper. It allows the user to determine cost and productivity, machine efficiency, and causes of delays for various system configurations. Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

THE EQUIPMENT STUDIED

The equipment modeled are grapple-type skidders and a whole-tree chipper with a self-loading grapple (figs. 1 and 2). The simulation assumes that the felling was done far enough in advance of the skidders so there is no conflict between fellers and the skidders and that wood to be skidded is always available.

MODEL OBJECTIVES

The primary objective of this model is a detailed look at productivity and efficiency of a given skidder-chipper combination (size of chipper, number and size of skidders). The trees to be skidded are assumed to be bunches left by earlier felling. The number of trees in each bunch can be obtained from the output of a feller/buncher simulation (Winsauer 1980, Winsauer and Bradley [In prep.]).

For input, the model requires data on the operating characteristics of the skidders and the chipper, the number of trees in each bunch, and stand conditions such as diameters of trees cut and skid distances.

After simulating the harvest of a stand, the model reports productivity figures for both types of equipment such as bunches, trees and volume skidded, trees and volumes chipped, and number of vans filled. Additional output gives the productive and delay times and causes for each type of equipment, etc.

SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation System (GPSS) with output subroutines written in FORTRAN. GPSS is a discrete event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up from a group of specific GPSS block types. These blocks then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Most versions of GPSS have a standard output format that contains all the data in a very concise form. The FORTRAN subroutines are used to present the output values of most interest in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a centi minute; i.e., 1/100 of a minute. The equipment works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot of solid wood.

It is assumed that the trees in the plot have already been felled and to some degree bunched by

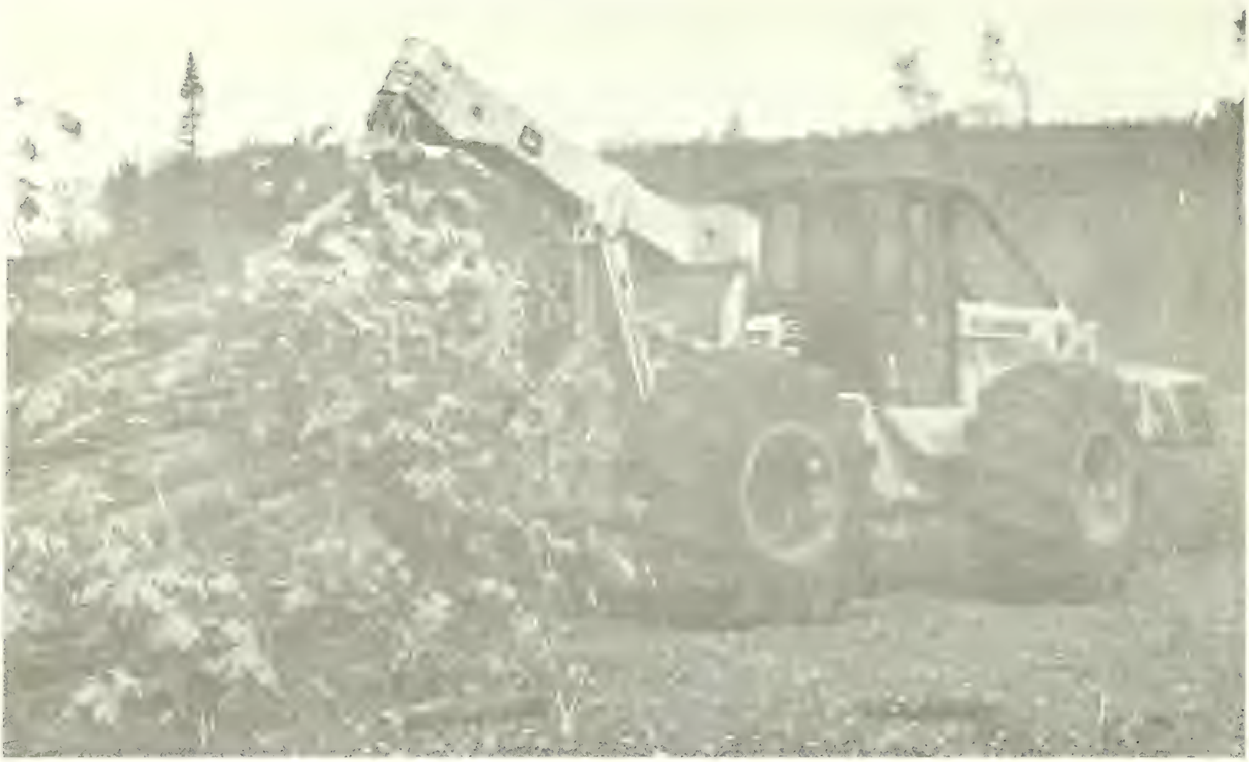

Figure 1.—*Grapple type skidder.*

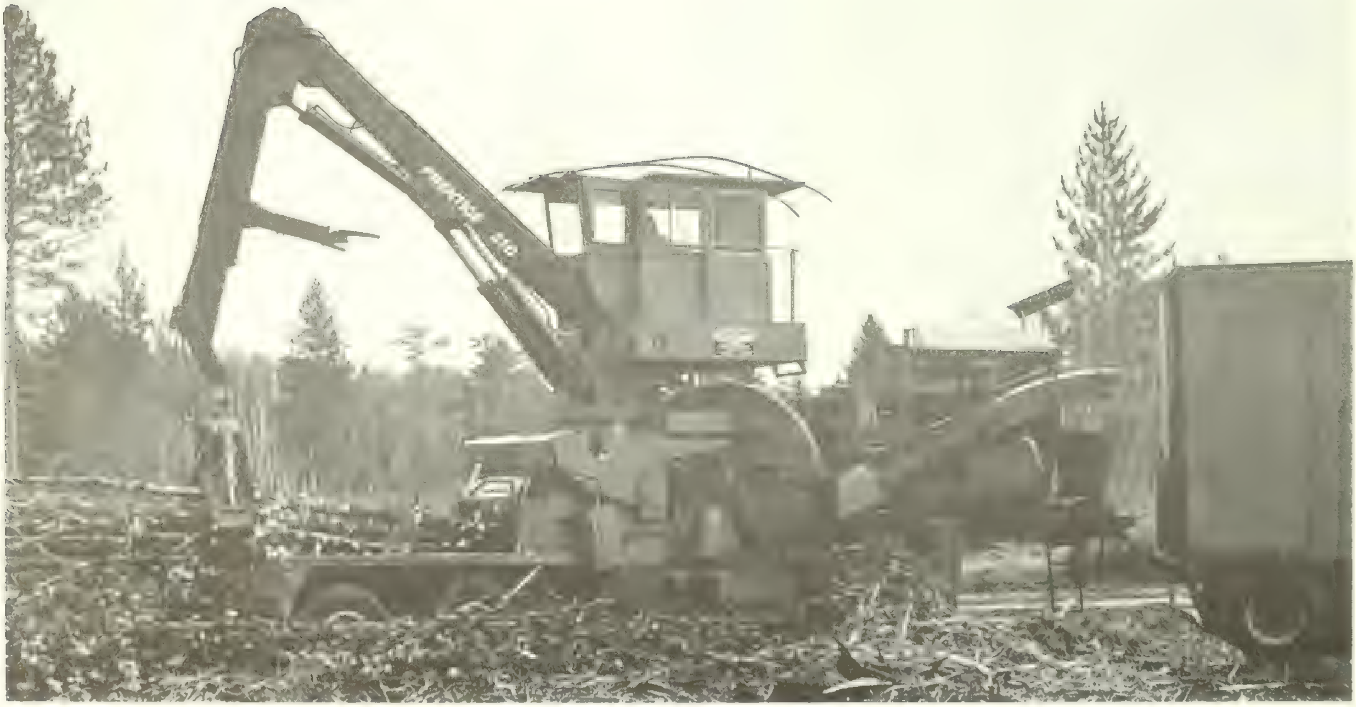

Figure 2.—*Whole-tree chipper.*

either man or machine. To obtain simulation results involving the interaction of feller and skidders, it would be necessary to combine this model with a felling model.

The following assumptions are made about the system:

1. The equipment works one shift a day, then is turned off for the remainder of 24 hours.
2. Production reports and statistics are produced at the end of each 24-hour day, so they include any overtime that may have been worked on a shift.
3. Two 15-minute coffee breaks and one 30-minute lunch break are scheduled each shift. The chipper can take a break only when the van is full. The skidders can break when they reach the landing if, and only if, the chipper is on break.
4. Each skidder travels from landing to the woods along a "skid road." It then travels through the woods to a bunch, grapples it, and hauls it to a collection point where it can drop trees and rebunch if desired. It also has the option of returning for a second bunch before hauling to the landing. The load is skidded back to the landing along the skid road.
5. There is limited space at the landing for wood, so the skidder may have to wait for room before dropping the load.
6. The skidders can quit for the day only if the chipper has quit. The skidder always drops the bunch before quitting.
7. There is room for one van at the chipper. When the van is full, the chipper must wait for it to be moved out and another van moved in.
8. A van is considered full when the volume in the van—after the last load added—is equal to or greater than the volume indicated in X$VANCY. Since the model uses hundredths of cubic feet, this value should also be in hundredths. The van capacity must also be measured in the same type of volume used in the models; i.e., solid wood.
9. The chipper can take a break or quit for the day only after it has finished filling a van.
10. One specific chipper delay has been incorporated into the model. For a certain percent of the chip loads, X$PDELY, the chipper is delayed while the log is bucked to fit into the chipper opening. By setting X$PDELY to zero, the user can eliminate this delay source.
11. To avoid carrying excessive data through the model, the skidders and chippers draw d.b.h. values for the trees from separate, but identical, distribution functions. In this way there is a 1 to 1 correspondence between trees skidded and trees chipped. This required function DBH and DIAM to be identical except for the random number generator; one uses RN4, the other, RN5. These random number generators must be given identical seed values.

MODEL DESCRIPTION

The model consists of three GPSS segments:

1. TIMER SEGMENT
2. SKIDDER SEGMENT
3. CHIPPER SEGMENT

and three FORTRAN subroutines for formatted (easily read) output.

The TIMER SEGMENT (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines to produce the formatted output. The TIMER signals the start of the day, the rest breaks and lunch (two 15-minute breaks a day and 1/2-hour lunch are assumed), and the end of the workday. The TIMER then completes the 24-hour day and produces an output report of the previous day's operation and production. Output is produced at the end of 24 hours, not at the end of the shift, to include the time needed to finish filling the last van before quitting for the day. If the required number of days have been simulated, the model shuts off. Otherwise, the start of another workday is signaled, and the process continues.

The SKIDDER SEGMENT (fig. 4) models one or more identical grapple-type skidders. Each skidder retrieves bunches of previously felled trees and skids them to a landing to be chipped.

The CHIPPER SEGMENT (fig. 5) models a whole-tree chipper with self-loading grapple. The chipper landing is located in or near the woods so that chip vans can be brought to the chipper.

DATA INPUT

GPSS accepts input data in several forms (table 1). For additional information on data types and card formats, see a GPSS Programming Manual (Schriber 1974).

Most of the data required in the main program are expected in the form of VARIABLES. VARIABLES can be defined in terms of the input data available at the end of the deck allowing the user flexibility in data form while avoiding card shuffling in the main program. For example, a skidding time

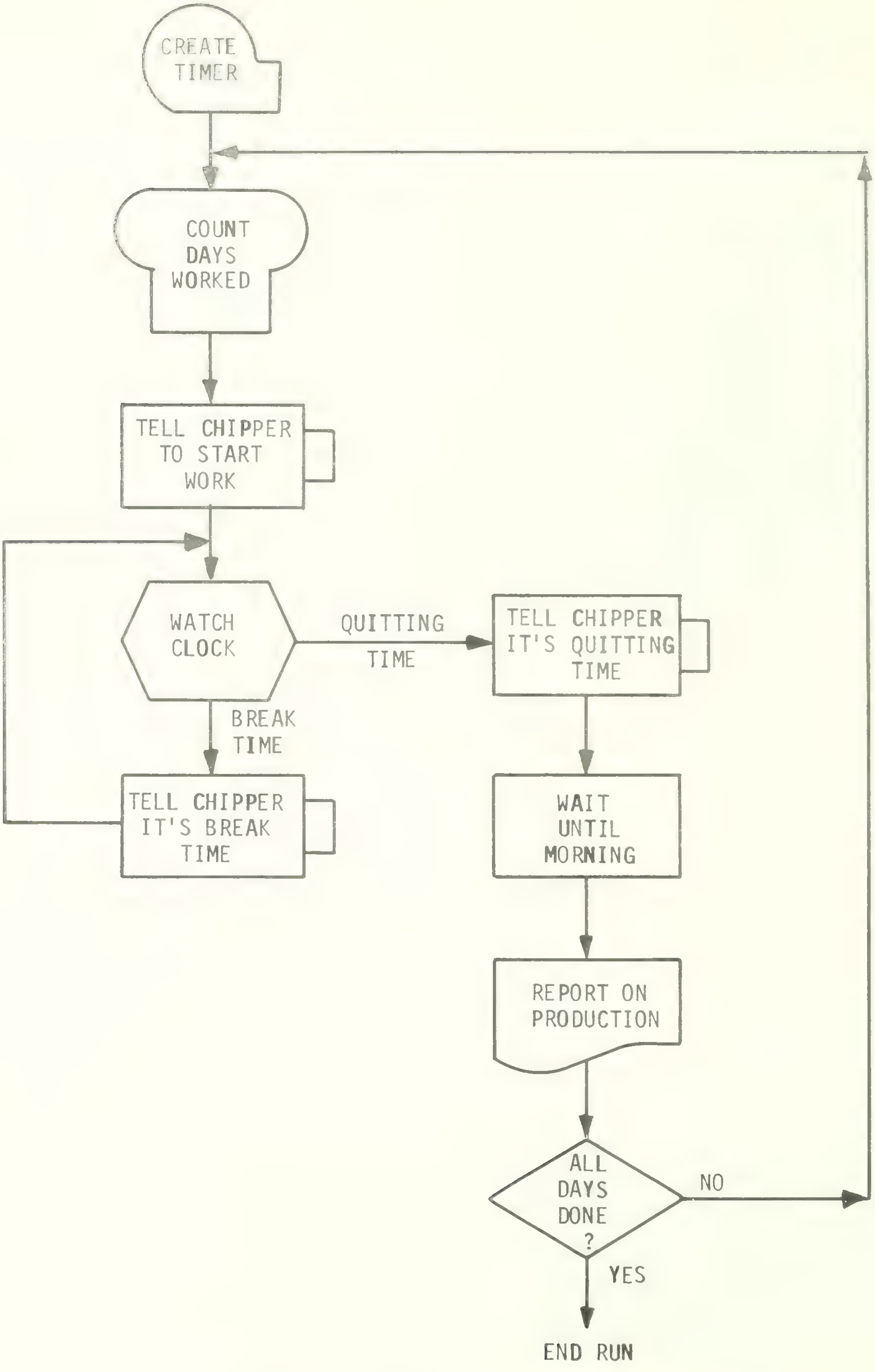

Figure 3.—*Timer segment--overview.*

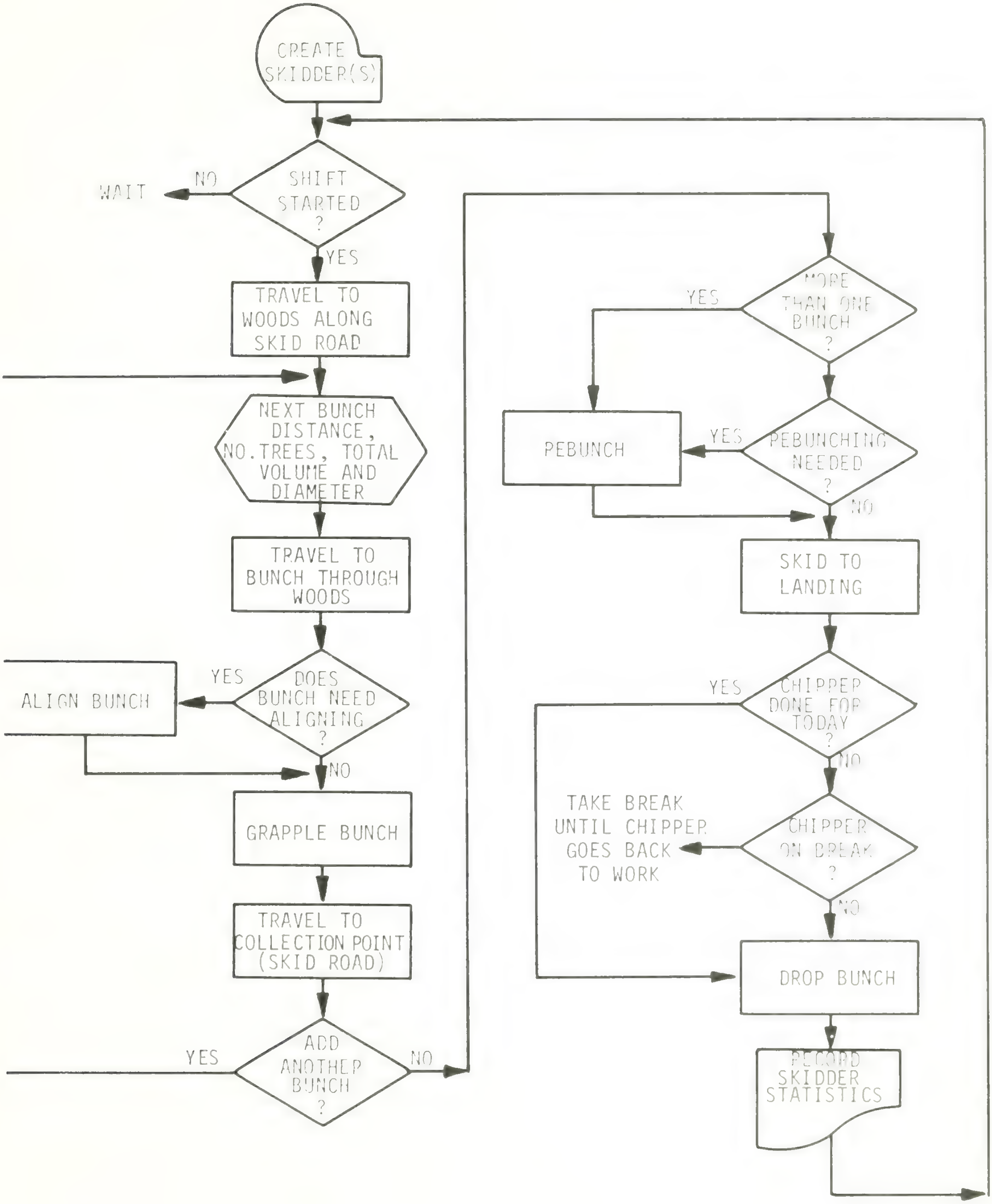
CREATE SKIDDER(S)
SHIFT STARTED ?
NO
WAIT
YES
TRAVEL TO WOODS ALONG SKID ROAD
NEXT BUNCH DISTANCE, NO.TREES, TOTAL VOLUME AND DIAMETER
TRAVEL TO BUNCH THROUGH WOODS
DOES BUNCH NEED ALIGNING ?
YES
ALIGN BUNCH
NO
GRAPPLE BUNCH
TRAVEL TO COLLECTION POINT (SKID ROAD)
ADD ANOTHER BUNCH ?
YES
NO
MORE THAN ONE BUNCH ?
YES
PEBUNCHING NEEDED ?
YES
PEBUNCH
NO
SKID TO LANDING
CHIPPER DONE FOR TODAY ?
YES
NO
CHIPPER ON BREAK ?
TAKE BREAK UNTIL CHIPPER GOES BACK TO WORK
NO
DROP BUNCH
RECORD SKIDDER STATISTICS

Figure 4.—*Skidder segment--overview.*

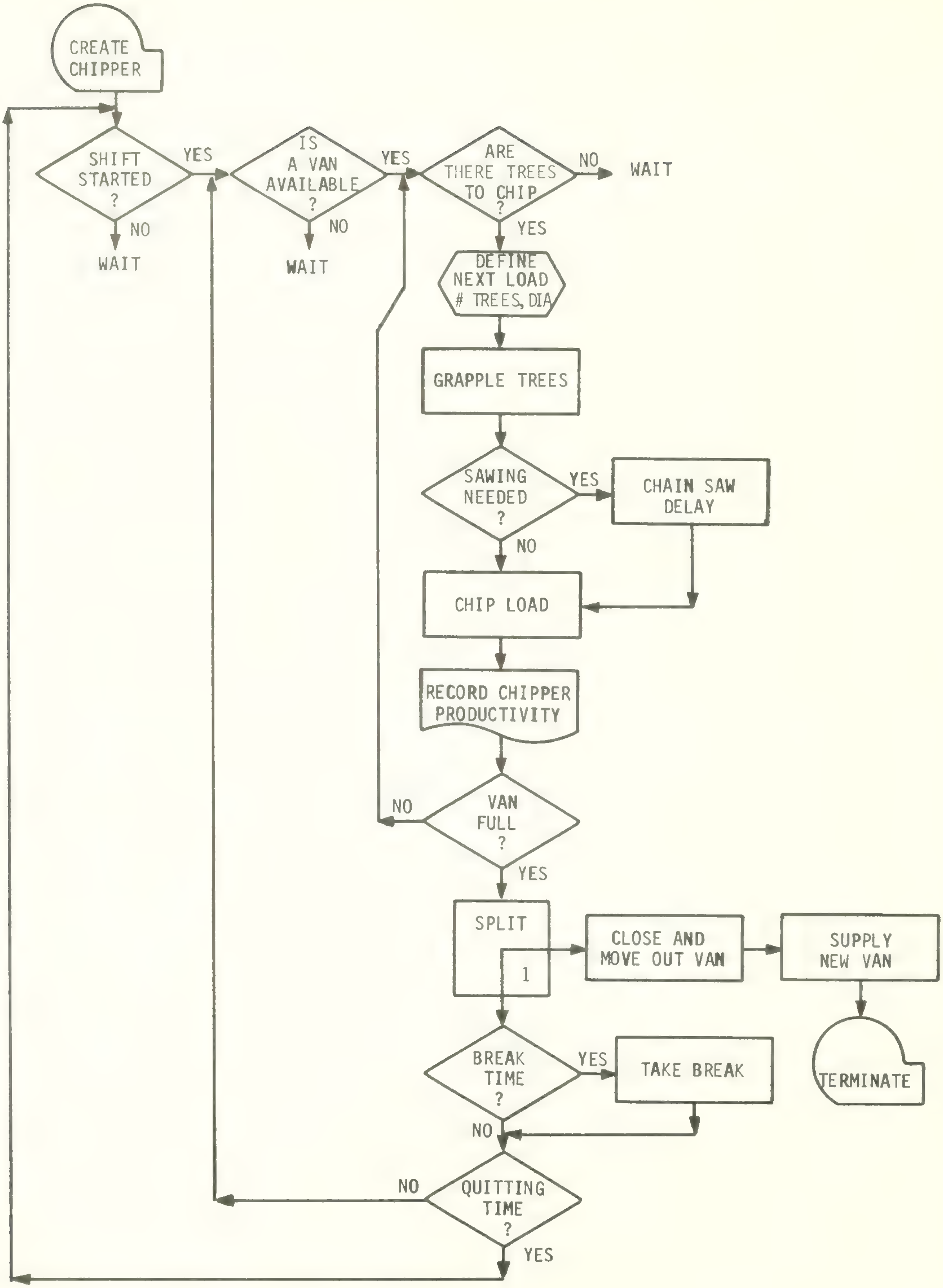

Figure 5.—*Chipper segment--overview.*

Table 1.—*GPSS data input forms*

Input data type	**Input form in GPSS**	**Example**
Simple averages or constants	Initialized SAVEVALUES	Average d.b.h. = 6 inches
Range of values	Initialized SAVEVALUES for mean and one-half width of interval	Shear time = 0.10 to 0.14 minutes = 0.12 ± 0.02 minutes
Equations	VARIABLES	Volume = $0.13\,\text{d.b.h.}^2 - 0.28$
Frequency distributions	FUNCTIONS	D.b.h. (inches) 4 5 6 7 8 Percent trees 23 25 30 15 5
Mean and variance for a standard distribution such as normal, Poisson exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with Mean = 10 Variance = 9

change from a constant (SAVEVALUE) to the product of rate times distance is accomplished by simply redefining the skid time variable and supplying the appropriate input cards.

The major exception to this convention is the use of SAVEVALUES (constants) for the summary values (average stand d.b.h., average tree height, etc.) that are entered simply for use in output tables. The actual input data cards follow the variable definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition.

DATA REQUIRED BY MODEL

Input data describing the equipment and harvesting operation must be supplied to run the simulation.

There are four types of data to be supplied:

1. Stand data (table 2)
2. Machine data for skidders (table 3)
3. Machine data for chipper (table 4)
4. Simulation run control (table 5).

The sample output presented in this paper results from a case study using the data in tables 2-5 as input. These data were gathered from time studies carried out during Forest Service projects and are used to illustrate the model and its use. Bunch size and location data were taken from a simulation run of a tracked type feller/buncher (Winsauer 1980).

The data in the tables are empirical, so they represent the operating characteristics of this machine under given stand conditions. Different harvest conditions will require new input data.

SIMULATION OUTPUT

The simulation run produces three pages of formatted output for each day of the run (figs. 6, 7, and 8). These present a summary of the stand data and cumulative productivity reports. Additional output is produced at the end of the run by the GPSS processor. This output supplies complete run details.

The first page of standard output (fig. 9) presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is primarily of value while debugging the model. The listing of the QUEUE statistics provides detailed information on how time is spent and delays for each type of equipment. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used.

Example:
CPHR = 4,230 = chipper hours x 100
CPTRE = 14,218 = trees chipped
CPVNS = 52 = vans filled
52/42.30 = 1.23 vans/hour
14,218/42.30 = 336 trees/hour
14,218/52 = 273.4 trees/van

The tables (figs. 10-11) provide additional details of the machine performance.

Table 2.—*Stand data*

Data required	Case study	Form required by program	Name
Average stand diameter	5.5 in d.b.h.	SAVEVALUE	X$AVDBH
Average stand volume	3,450 cu ft/acre	SAVEVALUE	X$AVVOL
Average tree height	43 ft	SAVEVALUE	X$AVHGT
Average trees/acre	844	SAVEVALUE	X$TRPAC
Density of wood	55 lb/cu ft	SAVEVALUE	X$LBCFT
Energy equivalent-fuel	150,000 BTU/gal	SAVEVALUE	X$FBTU
Energy equivalent-wood	8,000,000 BTU/ton	SAVEVALUE	X$WBTU
Skid distance-road/track	300 ft	VARIABLE	V$RDIST
Skid distance-woods	Distribution[1]	VARIABLE	V$WDIST

Distance (ft)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-100
Percent time	23	12	7	11	10	9	5	2	3	4	2	2	10

Actual tree diameter	Diameter distribution:	FUNCTION	FN$DBH FN$DIAM[2]

D.b.h (in.)	3	4	5	6	7	8	9
Percent trees	5	23	30	24	14	3	1

Tree volume	Volume (cu ft) $= -0.283 + 0.0031(\text{d.b.h.}^2)$ tree height $= 0.283 + 0.133(\text{d.b.h.}^2)$ assuming tree height = 43 ft	VARIABLE	V$TVOL
Type of feller/buncher	Tracked	SAVEVALUE	X$FBTYP
Number of feller/bunchers	1	SAVEVALUE	X$NUMFB
Feller/buncher fuel consumption	3.3 gal/ton	SAVEVALUE	X$FBGPT
Number of trees per bunch left by feller/buncher	Distribution-trees per bunch[1]	VARIABLE	V$NTBUN

Trees/bunch	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Percent bunches	0.4	2.1	3.5	3	6	5	4	6	5	4	6	7	6	3	5	4	3	3	4	4	3	4	4	6

---

[1] Distributions taken from simulation run of tracked feller/buncher (Winsauer 1980)

[2] FN$DBH and FN$DIAM are identical distribution functions used by skidders and chipper, respectively.

Table 3.—*Skidder data*

Data required	Case study	Form required by program	Name
Number of skidders	1	SAVEVALUE	X$NUMSK
Maximum gapple load (total sum of diameters)	150 inches	SAVEVALUE	X$MXSKD
Fuel consumption	4 gal/hr	SAVEVALUE	X$SKGPH
Travel time along skid road/track-based on distance	Distance/speed Road speed = 352 ft/min = 4 mph	VARIABLE	V$RTRAV
Travel time in woods-based on distance	Distance/woods speed Woods speed = ⅔ road speed	VARIABLE	V$WTRAV
Grapple time/bunch	Mean = 0.65 min Std. dev. = .20 min	VARIABLE	V$GRAPL
Time to align bunch, if needed	Mean = .50 min Std. dev. = .30 min	VARIABLE	V$ALIGN
Percent of bunches needing alignment before grappling	1 percent	SAVEVALUE	X$ALIGN
Drop time per load	Mean = .30 min Std. dev. = .15 min	VARIABLE	V$DROP
Rebunch time/load	Mean = .50 min Std. dev. = .25 min	VARIABLE	V$REBUN
Percent of single bunches needing to be rebunched before hauling	15 percent	SAVEVALUE	X$REBUN
Conditions under which the skidder will add another bunch before skidding to landing	Skid grapple load less than one/half its capacity	Boolean VARIABLE	BV$ADD

Table 4.—*Chipper and van data*

Data required	Case study	Form required by program	Name
Maximum chipper grapple load	12 trees	SAVEVALUE	X$CMAX
Room at landing	50 tree	SAVEVALUE	X$BUFLM
Chipper fuel consumption	5.7 gal/hr	SAVEVALUE	X$CPGPH
Actual grapple load	Distribution: trees/ grapple load	VARIABLE	V$NGRAP

Number of trees	1	2	3	4	5	6	7	8	9	10
percent of grapple loads	12	19	18	17	15	8	7	3	1	1

Data required	Case study	Form required by program	Name
Grapple and chip time/load	0.10 min per stem	VARIABLE	V$CHIP
Delay time for sawing	mean = 0.48 min Std. dev. = .09 min	VARIABLE	V$CHSAW
Percent of chip loads needing sawing	5 percent	SAVEVALUE	X$PDELY
Van capacity	1,000 cu ft (solid wood) (approximately 30 tons)	SAVEVALUE	X$VANCY
Time to close van	1 minute	VARIABLE	VSCLSVN
Time to change vans	4 minutes	VARIABLE	VSVNWAT

Table 5.—*Simulation run control*

Data required		**Case study**	**Form required by program**
Random number generators	Random number	Use	
	1	GPSS scheduler	RMULT CARD
	2	Generate normal random distributions	
	3	FUNCTIONS for wood distance, trees/bunch, chipper-grapple load	
	4, 5	Diameter distributions-these should have identical seed values and not be used for any other functions	
Number of days to simulate	5		START CARD
Standard output	Every fifth day		START CARD

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves random numbers, only a sample of what could happen. If the model is run again with different random numbers, the results will be different. An average over several days or several runs is the best estimate of an actual system.

KNOWN DIFFERENCES BETWEEN SYSTEMS

The program listed in the Appendix is operational on a UNIVAC 1110 under an implementation of GPSS called GPSS-X8, obtained through Use Program Library Interchange (UPLI). It should run under most GPSS processors with only minor changes. The following should be checked for your system.

INITIAL cards—In GPSS-X8 the INITIAL cards appear last in the deck. They should be moved to the head of the deck for most other GPSS processors.

JOB CONTROL cards—These are unique to each computer lab and must be obtained locally.

HELP BLOCKS—In GPSS-X8 HELP BLOCKS (lines 105-152 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted; the subroutine cannot pass arguments back to GPSS.

Some versions of GPSS do not allow HELP BLOCKS. In this case the program can be run without lines 105 to 152 and the data obtained instead from the standard output. If some form of HELP BLOCKS are allowed, the HELP BLOCKS formats and the subroutines may have to be changed. See the GPSS manual for your computer installation.

CONCLUSIONS

The simulation model provides an in-depth look at the operation of the system. This makes it possible to determine the effect on productivity and type of delays caused by changes in the system (table 6) or the stand. It can also be used in conjunction with other models to determine the cost and feasibility of a complete harvesting operation.

Some knowledge of GPSS allows the user to modify the model to meet his exact needs, making it even more useful and realistic.

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```
                              SAWLOG  SORTING  SIMULATOR
                                  DEVELOPED  BY  THE
                      NORTH CENTRAL FOREST  EXPERIMENT  STATION
                    FOREST  SERVICE, U. S. DEPT.  OF  AGRICULTURE
     FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                     AND  THE
                FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN
                                      AUTHORS
                            DENNIS P. BRADLEY, ECONOMIST
                           SHARON A. WINSAUER, PROGRAMMER

I.  STAND CHARACTERISTICS.
     3450.00 CUFT., AVERAGE VOLUME PER ACRE.
        5.50 INCHES, AVERAGE DBH.
       43.00 FEET, AVERAGE TREE HEIGHT.
      844.00 AVERAGE NUMBER OF TREES PER ACRE.
        7.18 FEET, AVERAGE TREE SPACING.

II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
  A.  FELLER-BUNCHERS.                   1  MACHINE(S)     TRACKED TYPE

  B.  SKIDDERS.                   1  MACHINE(S)     RUBBER-TIRED GRAPPLE SKIDDER(S).

        MAXIMUM SKID BUNCH HAS TOTAL SUM OF DIAMETER  150.00 INCHES


  C.  CHIPPER-LOADER.
        THE LOADER CAN TAKE A LOAD OF   12.TREES
      ENERGY BALANCE
              .33 GAL/TON - FELLER BUNCHER
              .10 GAL/TON - SKIDDER
              .14 GAL/TON - CHIPPER
              .57 TOTAL GAL/TON .
         85719.38 BTU/TON USED AS FUEL
       8000000.00 BTU/TON HARVESTED FROM WOOD

            93.33     ENERGY BENEFIT RATIO.
```

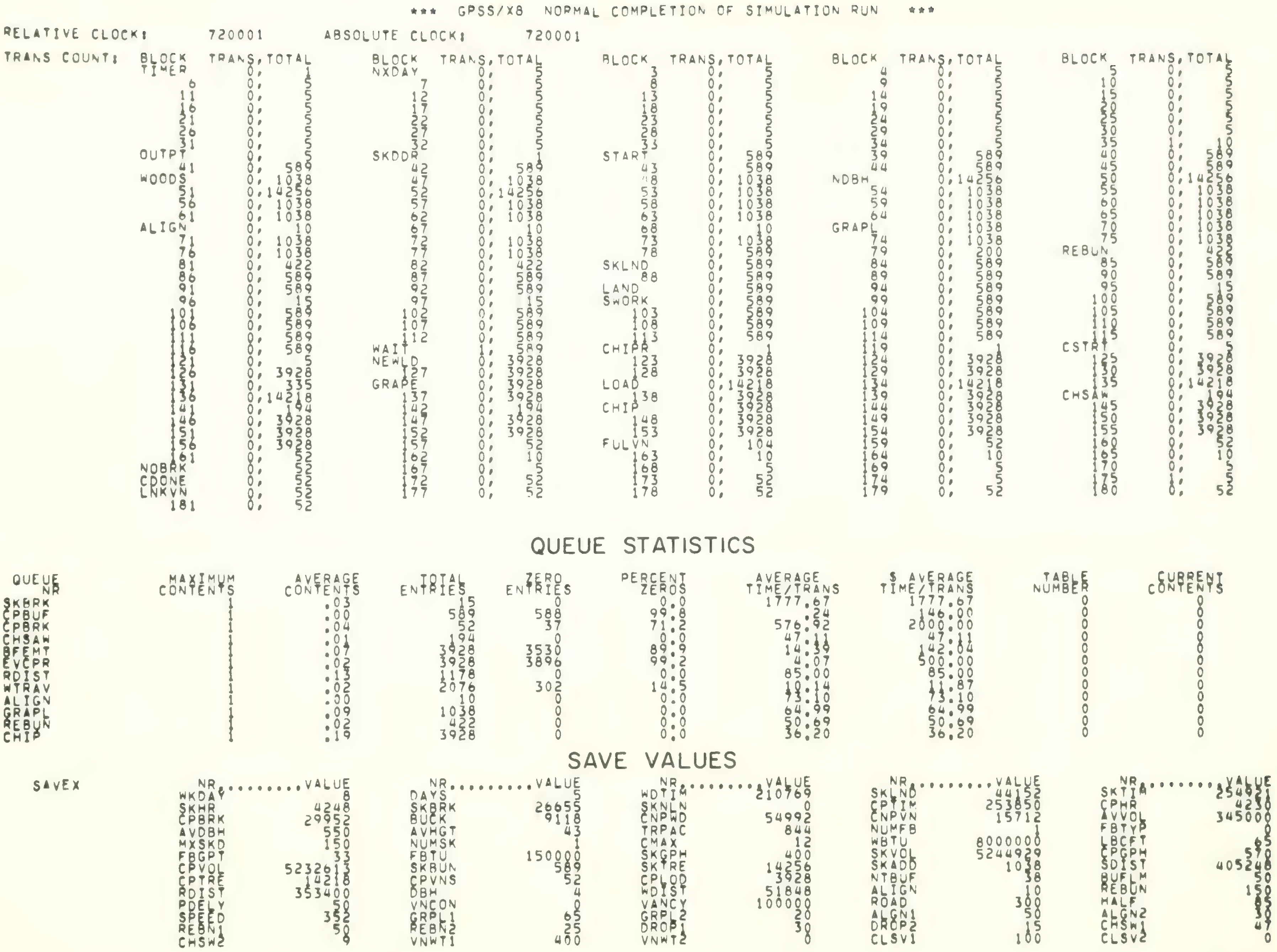
Figure 6.—*Simulation output--system and stand characteristics.*

```
          S K I D D I N G   P R O D U C T I O N   A N D   C O S T   S U M M A R Y


***********************************************************************************************
I.    A.   42.48      HOURS WORKED BY SKIDDER(S).
      B.    1         NUMBER OF SKIDDER(S).
II.   A.  589         BUNCHES SKIDDED - ALL MACHINES.
                   1.76     AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES COLLECTED.
                  24.20     AVERAGE NUMBER OF TREES PER SKIDDER BUNCH.
      B.14256         TREES SKIDDED - ALL MACHINES.
      C.52449.29      VOLUME SKIDDED - CU.FT. - ALL MACHINES.
      D.  405248      TOTAL DISTANCE SKIDDED.
      E. 1704.60      TOTAL TONS SKIDDED - ALL MACHINES.

III.  A.   13.87      BUNCHES SKIDDED PER MACHINE HOUR.
      B.  335.59      TREES SKIDDED PER MACHINE HOUR.
      C. 1234.68      VOL. SKIDDED PER MACHINE HOUR. - CU.FT.
      D.   40.13      TONS SKIDDED PER MACHINE HOUR.
IV.   A.  344.01      AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET.
      B.    4.33      AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES.
                   3.58     TIME - LANDING TO WOODS AND RETURN.
                    .30     PRODUCTIVE TIME - LANDING ACTIVITY.
                    .00     NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.
                    .45     TIME ON BREAKS
V.    A.  169.92      TOTAL GALLONS USED.
                   4.00     GALLONS PER HOUR.
                    .10     GALLONS PER TON.
```

Figure 7.—*Simulation output--skidder productivity.*

```
         C H I P P E R - L O A D E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y
******************************************************************************************************
I.    A.   42.30     HOURS WORKED BY CHIPPER-LOADER.

II.   A. 3928        LOADS CHIPPED.
                    3.62     AVERAGE NUMBER OF STEMS PER LOAD.
                   13.32     AVERAGE VOLUME PER LOAD - CU.FT.
      B.   14218     TREES CHIPPED.
      C.52326.13     VOLUME CHIPPED - CU.FT.
      D. 1700.60     TONS CHIPPED.
      E.      52     VANS FILLED.
                   75.54     AVERAGE NUMBER OF LOADS PER VAN.
                 1006.27     AVERAGE VOLUME PER VAN - CU.FT.
                   32.70     AVERAGE TONS PER VAN.

III.  A.   92.86     LOADS CHIPPED PER MACHINE HOUR.
      B.  336.12     TREES CHIPPED PER MACHINE HOUR.
      C. 1237.02     VOLUME CHIPPED PER MACHINE HOUR - CU.FT.
      D.   40.20     TONS CHIPPED PER MACHINE HOUR.
      E.    1.23     VANS FILLED PER MACHINE HOUR.

IV.   A.   48.81     AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES - MINUTES.
                   27.70     PRODUCTIVE TIME PER VAN - MINUTES.
                   21.11     NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MINUTES.
                          10.58     LOADER WAITING FOR WOOD FROM SKIDDERS - MINUTES.
                           3.02     CHIPPER WAITING FOR VANS TO FILL - MINUTES.
                           1.75     BUCKING TIME
                           5.76     BREAK TIME

VI.   A.  241.11     TOTAL GALLONS OF FUEL USED.
                    5.70     GALLONS/HOUR.
                     .14     GALLONS/TON.
```

Figure 8.—*Simulation output--chipper productivity.*



```
                                 ***  GPSS/X8  NORMAL COMPLETION OF SIMULATION RUN   ***
RELATIVE CLOCK:      720001      ABSOLUTE CLOCK:      720001
TRANS COUNT:  BLOCK   TRANS,TOTAL    BLOCK   TRANS,TOTAL    BLOCK   TRANS,TOTAL    BLOCK   TRANS,TOTAL    BLOCK   TRANS,TOTAL
              TIMER       0,    1    NXDAY       0,    5        3       0,    5        4       0,    5        5       0,    5
                  6       0,    5        7       0,    5        8       0,    5        9       0,    5       10       0,    5
                 11       0,    5       12       0,    5       13       0,    5       14       0,    5       15       0,    5
                 16       0,    5       17       0,    5       18       0,    5       19       0,    5       20       0,    5
                 21       0,    5       22       0,    5       23       0,    5       24       0,    5       25       0,    5
                 26       0,    5       27       0,    5       28       0,    5       29       0,    5       30       0,    5
                 31       0,    5       32       0,    5       33       0,    5       34       0,    5       35       1,   10
              OUTPT       0,    5    SKDDR       0,    1    START       0,  589       39       0,  589       40       0,  589
                 41       0,  589       42       0,  589       43       0,  589       44       0,  589       45       0,  589
              WOODS       0, 1038       47       0, 1038       48       0, 1038    NDBH        0,14256       50       0,14256
                 51       0,14256       52       0,14256       53       0, 1038       54       0, 1038       55       0, 1038
                 56       0, 1038       57       0, 1038       58       0, 1038       59       0, 1038       60       0, 1038
                 61       0, 1038       62       0, 1038       63       0, 1038       64       0, 1038       65       0, 1038
              ALIGN       0,   10       67       0,   10       68       0,   10    GRAPL       0, 1038       70       0, 1038
                 71       0, 1038       72       0, 1038       73       0, 1038       74       0, 1038       75       0, 1038
                 76       0, 1038       77       0, 1038       78       0,  589       79       0,  200    REBUN       0,  422
                 81       0,  422       82       0,  422    SKLND       0,  589       84       0,  589       85       0,  589
                 86       0,  589       87       0,  589       88       0,  589       89       0,  589       90       0,  589
                 91       0,  589       92       0,  589    LAND        0,  589       94       0,  589       95       0,   15
                 96       0,   15       97       0,   15    SWORK       0,  589       99       0,  589      100       0,  589
                101       0,  589      102       0,  589      103       0,  589      104       0,  589      105       0,  589
                106       0,  589      107       0,  589      108       0,  589      109       0,  589      110       0,  589
                111       0,  589      112       0,  589      113       0,  589      114       0,  589      115       0,  589
                116       0,  589    WAIT        1,  589    CHIPR       0,    1      119       0,    1    CSTRT       0,    5
                121       0,    5    NEWLD       0, 3928      123       0, 3928      124       0, 3928      125       0, 3928
                126       0, 3928      127       0, 3928      128       0, 3928      129       0, 3928      130       0, 3928
                131       0,  335    GRAPE       0, 3928    LOAD        0,14218      134       0,14218      135       0,14218
                136       0,14218      137       0, 3928      138       0, 3928      139       0, 3928    CHSAW       0,  194
                141       0,  194      142       0,  194    CHIP        0, 3928      144       0, 3928      145       0, 3928
                146       0, 3928      147       0, 3928      148       0, 3928      149       0, 3928      150       0, 3928
                151       0, 3928      152       0, 3928      153       0, 3928      154       0, 3928      155       0, 3928
                156       0, 3928      157       0,   52    FULVN       0,  104      159       0,   52      160       0,   52
                161       0,   52      162       0,   10      163       0,   10      164       0,   10      165       0,   10
              NOBRK       0,   52      167       0,    5      168       0,    5      169       0,    5      170       0,    5
              CDONE       0,   52      172       0,   52      173       0,   52      174       0,    5      175       1,    5
              LNKVN       0,   52      177       0,   52      178       0,   52      179       0,   52      180       0,   52
                181       0,   52
```

QUEUE STATISTICS

```
QUEUE     MAXIMUM    AVERAGE    TOTAL    ZERO     PERCENT     AVERAGE     $ AVERAGE     TABLE    CURRENT
   NR    CONTENTS   CONTENTS  ENTRIES  ENTRIES     ZEROS   TIME/TRANS   TIME/TRANS    NUMBER   CONTENTS
SKBRK           1        .03       15        0       0.0      1777.67      1777.67         0          0
CPBUF           1        .00      589      588      99.8          .24       146.00         0          0
CPBRK           1        .04       52       37      71.2       576.92      2000.00         0          0
CHSAW           1        .01      194        0       0.0        47.11        47.11         0          0
BFEMT           1        .07     3928     3530      89.9        14.39       142.04         0          0
EVCPR           1        .02     3928     3896      99.2         4.07       500.00         0          0
RDIST           1        .13     1178        0       0.0        85.00        85.00         0          0
WTRAV           1        .02     2076      302      14.5        10.14        11.87         0          0
ALIGN           1        .00       10        0       0.0        73.10        73.10         0          0
GRAPL           1        .09     1038        0       0.0        64.99        64.99         0          0
REBUN           1        .02      422        0       0.0        50.69        50.69         0          0
CHIP            1        .19     3928        0       0.0        36.20        36.20         0          0
```

SAVE VALUES

```
SAVEX      NR.........VALUE    NR.........VALUE    NR.........VALUE    NR.........VALUE    NR.........VALUE
        WKDAY             8 DAYS              5 WDTIM        210769 SKLND         44152 SKTIM        254921
        SKHR           4248 SKBRK         26655 SKNLN             0 CPTIM        253850 CPHR           4230
        CPBRK         29952 BUCK           9118 CNPWD         54992 CNPVN         15712 AVVOL        345000
        AVDBH           550 AVHGT            43 TRPAC           844 NUMFB             1 FBTYP             0
        MXSKD           150 NUMSK             1 CMAX             12 WBTU        8000000 LBCFT            65
        FBGPT            33 FBTU         150000 SKGPH           400 SKVOL       5244929 CPGPH           570
        CPVOL       5232613 SKBUN           589 SKTRE         14256 SKADD          1038 SDIST        405248
        CPTRE         14218 CPVNS            52 CPLOD          3928 NTBUF            38 BUFLM            50
        RDIST        353400 DBH               4 WDIST         51848 ALIGN            10 REBUN           150
        PDELY            50 VNCON             0 VANCY        100000 ROAD            300 HALF             85
        SPEED           352 GRPL1            65 GRPL2            20 ALGN1            50 ALGN2            30
        REBN1            50 REBN2            25 DROP1            30 DROP2            15 CHSW1            47
        CHSW2             9 VNWT1           400 VNWT2             0 CLSV1           100 CLSV2             0
```

Figure 9.—*Standard GPSS output.*

SKIDDER - TIME IN WOODS (MIN. X 100)

```
TABLE            ENTRIES IN TABLE        MEAN ARGUMENT       STANDARD DEVIATION       SUM OF ARGUMENTS
WDTIM                  589                  357.84                  84.01                  210769.
      UPPER         OBSERVED       PERCENT       CUMULATIVE      CUMULATIVE      MULTIPLE       DEVIATION
      LIMIT         FREQUENCY      OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN        FROM MEAN
        250               80         13.58           13.6            86.4            .69           -1.28
        300               91         15.45           29.0            71.0            .83            -.68
        350               86         14.60           43.6            56.4            .97            -.09
        400              142         24.11           67.7            32.3           1.12             .50
        450              123         20.88           88.6            11.4           1.26            1.10
        500               37          6.28           94.9             5.1           1.40            1.69
        550               21          3.57           98.5             1.5           1.54            2.29
        600                7          1.19           99.7              .3           1.68            2.88
        650                1           .17           99.8              .1           1.82            3.48
        700                1           .17          100.0              .0           1.96            4.07
```

NUMBER OF TREES PER SKIDDER BUNCH

```
TABLE            ENTRIES IN TABLE        MEAN ARGUMENT       STANDARD DEVIATION       SUM OF ARGUMENTS
BNTRE                  589                   24.20                   6.03                   14256.
      UPPER         OBSERVED       PERCENT       CUMULATIVE      CUMULATIVE      MULTIPLE       DEVIATION
      LIMIT         FREQUENCY      OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN        FROM MEAN
         16               37          6.28            6.3            93.7            .66           -1.36
         18               75         12.73           19.0            81.0            .74           -1.03
         20               84         14.26           33.3            66.7            .82            -.69
         22               64         10.87           44.1            55.9            .90            -.36
         24               91         15.45           59.6            40.4            .99            -.03
         26               64         10.87           70.5            29.5           1.07             .29
         28               38          6.45           76.9            23.1           1.16             .62
         30               32          5.43           82.3            17.7           1.24             .96
         32               32          5.43           87.8            12.2           1.32            1.29
         34               20          3.40           91.2             8.8           1.40            1.62
         36               27          4.58           95.8             4.2           1.49            1.95
         38               17          2.89           98.6             1.4           1.57            2.29
OVERFLOW                   8          1.36          100.0              .0
```

VOLUME PER SKIDDER BUNCH (CU. FT. X 100)

```
TABLE            ENTRIES IN TABLE        MEAN ARGUMENT       STANDARD DEVIATION       SUM OF ARGUMENTS
BNVOL                  589                 8904.80                2246.71                 5244929.
      UPPER         OBSERVED       PERCENT       CUMULATIVE      CUMULATIVE      MULTIPLE       DEVIATION
      LIMIT         FREQUENCY      OF TOTAL      PERCENTAGE      REMAINDER       OF MEAN        FROM MEAN
       5000                1           .17             .1            99.8            .56           -1.74
       5500                2           .34             .5            99.5            .61           -1.52
       6000               20          3.40            3.9            96.1            .67           -1.29
       6500               52          8.83           12.7            87.3            .73           -1.07
       7000               59         10.02           22.8            77.2            .78            -.84
       7500               60         10.19           32.9            67.1            .84            -.62
       8000               51          8.66           41.6            58.4            .89            -.40
       8500               51          8.66           50.3            49.7            .95            -.18
       9000               48          8.15           58.4            41.6           1.01             .04
       9500               46          7.81           66.2            33.8           1.07             .26
      10000               39          6.62           72.8            27.2           1.12             .48
      10500               21          3.57           76.4            23.6           1.18             .71
      11000               29          4.92           81.3            18.7           1.24             .93
      11500               23          3.90           85.2            14.8           1.29            1.16
      12000               20          3.40           88.6            11.4           1.35            1.38
      12500               10          1.70           90.3             9.7           1.40            1.60
      13000               15          2.55           92.9             7.1           1.46            1.82
      13500               13          2.21           95.1             4.9           1.52            2.05
      14000               15          2.55           97.6             2.4           1.57            2.27
      14500                8          1.36           99.0             1.0           1.63            2.49
      15000                4           .67           99.7              .3           1.68            2.71
      15500                2           .34          100.0              .0           1.74            2.94
```

Figure 10.—*Simulation output--productivity tables I.*

VOLUME PER CHIPPER LOAD (CU. FT. X 100)

```
TABLE        ENTRIES IN TABLE     MEAN ARGUMENT     STANDARD DEVIATION     SUM OF ARGUMENTS
CPVOL              3928              1332.13               815.81                5232613.

     UPPER      OBSERVED      PERCENT      CUMULATIVE      CUMULATIVE      MULTIPLE      DEVIATION
     LIMIT      FREQUENCY     OF TOTAL     PERCENTAGE      REMAINDER       OF MEAN       FROM MEAN
      200            145         3.69            3.7            96.3            .15          -1.39
      400            243         6.19            9.9            90.1            .30          -1.14
      600            291         7.41           17.3            82.7            .45           -.89
      800            502        12.78           30.1            69.9            .60           -.65
     1000            404        10.29           40.4            59.6            .75           -.40
     1200            327         8.32           48.7            51.3            .90           -.16
     1400            439        11.18           59.9            40.1           1.05            .08
     1600            323         8.22           68.1            31.9           1.20            .32
     1800            247         6.29           74.4            25.6           1.35            .57
     2000            241         6.14           80.5            19.5           1.50            .81
     2200            225         5.73           86.2            13.8           1.65           1.06
     2400            146         3.72           89.9            10.1           1.80           1.31
     2600            101         2.57           92.5             7.5           1.95           1.55
     2800             76         1.93           94.5             5.5           2.10           1.80
     3000             66         1.68           96.1             3.9           2.25           2.04
     3200             50         1.27           97.4             2.6           2.40           2.29
     3400             32          .81           98.2             1.8           2.55           2.53
     3600             11          .28           98.5             1.5           2.70           2.78
     3800             18          .45           99.0             1.0           2.85           3.03
     4000             11          .28           99.2              .7           3.00           3.27
     4200              8          .20           99.4              .5           3.15           3.52
     4400              4          .10           99.5              .4           3.30           3.76
     4600              8          .20           99.7              .2           3.45           4.01
     4800              3          .07           99.8              .1           3.60           4.25
     5000              4          .10           99.9              .0           3.75           4.50
     5200              2          .05          100.0              .0           3.90           4.74
     5400              1          .02          100.0              .0           4.05           4.99
```

CHIP TIME PER LOAD (MIN. X 100)

```
TABLE        ENTRIES IN TABLE     MEAN ARGUMENT     STANDARD DEVIATION     SUM OF ARGUMENTS
CPTIM              3928               56.99                71.65                 223850.

     UPPER      OBSERVED      PERCENT      CUMULATIVE      CUMULATIVE      MULTIPLE      DEVIATION
     LIMIT      FREQUENCY     OF TOTAL     PERCENTAGE      REMAINDER       OF MEAN       FROM MEAN
       20           1160        29.53           29.5            70.5            .35           -.51
       40           1189        30.27           59.8            40.2            .70           -.23
       60            742        18.89           78.7            21.3           1.05            .04
       80            331         8.43           87.1            12.9           1.40            .32
      100            111         2.83           89.9            10.1           1.75            .60
      120             71         1.81           91.8             8.2           2.11            .87
      140             44         1.12           92.9             7.1           2.46           1.16
      160             30          .76           93.6             6.4           2.81           1.44
      180             32          .81           94.5             5.5           3.16           1.72
      200             20          .50           95.0             5.0           3.51           2.00
      220             31          .78           95.7             4.3           3.86           2.28
      240             27          .68           96.4             3.6           4.21           2.55
      260             27          .68           97.1             2.9           4.56           2.83
      280             23          .58           97.7             2.3           4.91           3.11
      300             13          .33           98.0             2.0           5.26           3.39
      320             14          .35           98.4             1.6           5.62           3.67
      340              9          .22           98.6             1.4           5.97           3.95
      360              6          .15           98.8             1.2           6.32           4.23
      380              4          .10           98.9             1.1           6.67           4.51
      400              4          .10           99.0             1.0           7.02           4.79
      420              4          .10           99.1              .9           7.37           5.07
      440              1          .02           99.1              .8           7.72           5.35
      460              1          .02           99.1              .8           8.07           5.62
      480              2          .05           99.2              .8           8.42           5.90
      520             10          .25           99.4              .5           9.12           6.46
      540             13          .33           99.8              .2           9.48           6.74
      560              6          .15           99.9              .0           9.83           7.02
      580              2          .05          100.0              .0          10.18           7.30
OVERFLOW               1          .02          100.0              .0
```

Figure 11.—*Simulation output--productivity tables II.*

Table 6.—*Productivity and delays of two system configurations*

	System 1		System 2	
	One skidder	One chipper	Two skidders	One chipper
Total machine hours worked	42.39	42.21	81.06	40.42
Percent productive time	89.7	56.6	59.6	75.4
Percent nonproductive time				
Total delay	10.3	43.3	40.4	24.6
Breaks	10.3	11.8	6.6	12.4
Wait to drop wood	0.0		33.8	
Wait for wood to chip		21.9		0.0
Wait for bucking		3.3		4.6
Wait for vans		6.3		7.6
Total trees	14,268		17,843	
Total vans filled	52		65	
Total tons processed	1,706		2,132	

APPENDIX A
VARIABLE LISTS AND DEFINITIONS

IMPLICIT TIME UNIT—centi-minute
MODEL SEGMENTS, TRANSACTIONS, AND PARAMETERS

Segment 1—TIMER
Transactions—1 time keeper.
Parameters—None.

Segment 2—SKIDDER(S)
Transactions—One for each skidder.
Parameters
P1—not used.
P2—clock time.
P3—total number of trees in skid load.
P4—total d.b.h. (inches) in skid load.
P5—total volume of skid load.
P6—number of feller/buncher bunches combined in this skid load.
P7—road distance.
P8—woods distance.
P9—number of trees in feller/buncher bunch.
P10—counter for d.b.h. loop.
P11—total sum of diameter in feller/buncher bunch.
P12—total volume of feller/buncher bunch.

Segment 3—CHIPPER
Transactions—One chipper-loader. When it splits, parent transaction remains as chipper while offspring becomes full van.
Parameters
P1—clock time.
P2—number of trees in chipper-grapple load.
P3—volume of load.
P4—sum of diameter of load (inches).
P5—loop counter.

FACILITY

CPBUF	Chipper buffer—area where skidders drop logs within reach of chipper.

FUNCTIONS

DBH	Distribution of diameters in the stand—used by skidder.
DIAM	Identical diameter distribution—used by chipper.
NGRAP	Distribution of the number of trees per chipper—grapple load.

NTBUN	Distribution of number of trees in each bunch left by feller/buncher.
SNORM	Used to obtain a normal distribution for sampling.
WDIST	Distribution of bunches in the woods.

QUEUES

ALIGN	Time skidder spends aligning bunches.
BFEMT	Time chipper waits for wood.
CHIP	Chipping time.
CHSAW	Time spent bucking logs.
CPBRK	Time chipper spends on break.
CPBUF	Skidder time waiting to drop load.
EVCPR	Chipper time waiting for empty van.
GRAPL	Skidder grapple time.
RDIST	Skidder travel time on road.
REBUN	Time spent rebunching a skid load.
SKBRK	Time skidders spend on break.
WTRAV	Skidder travel time in woods.

SAVEVALUES

ALGN1	Time to align bunch—mean (centi-minutes).
ALGN2	Time to align bunch—standard deviation (centi-minutes).
ALIGN	Percent of bunches needing alignment. NOTE: Must be three digits in terms of thousandths.
AVDBH	Average stand diameter (inches x 10).
AVHGT	Average tree height (feet).
AVVOL	Average stand volume (cubic feet x 100).
BUCK	Chipper delay time due to bucking (centi-minutes).
BUFLM	Available room at chipper (number of logs).
CHSW1	Chain saw time to buck log—mean (centi-minutes).
CHSW2	Chain saw time—standard deviation (centi-minutes).
CLSV1	Time to close van—mean (centi-minutes).
CLSV2	Time to close van—standard deviation (centi-minutes).
CMAX	Maximum chipper load (number of trees).
CNPVN	Chipper nonproductive time waiting for vans (centi-minutes).
CNPWD	Chipper nonproductive time waiting for wood to chip (centi-minutes).
CPBRK	Chipper time spent on breaks (centi-minutes).
CPGPH	Chipper fuel consumption (gallons/hour).
CPHR	Total chipper time (hours x 100).
CPLOD	Total number of chipper-grapple loads chipped.
CPTIM	Total chipper time (centi-minutes).
CPTRE	Total trees chipped.
CPVNS	Total vans filled.
CPVOL	Total volume chipped (cubic feet x 100).
DAYS	Number of current day.
DBH	Diameter of current tree (inches).
DROP1	Time needed for skidder to drop bunch—mean (centi-minutes).
DROP2	Time needed to drop bunch—standard deviation (centi-minutes).
FBGPT	Feller/buncher fuel usage (gallons/ton).
FBTU	Btu's in fuel per gallon.
FBTYP	Feller/buncher type. 0 = tracked; 1 = rubber tired.
GRPL1	Skidder grapple time/bunch—mean (centi-minutes).
GRPL2	Grapple time/bunch—standard deviation (centi-minutes).
HALF	Skid load limit to add more to the load (sum of diameters).
LBCFT	Density of wood (pounds/cubic feet).
MXSKD	Maximum skidder grapple load—total sum of diameter (inches).
NTBUF	Current number of trees at the chipper.
NUMFB	Number of feller/bunchers used to fell trees.
NUMSK	Number of skidders in operation.
PDELY	Percent of chipper loads requiring sawing. NOTE: Must be three digits in terms of thousandths.
RDIST	Skid road/track distance (feet).
REBN1	Time needed to rebunch skid load—mean (centi-minutes).
REBN2	Time needed to rebunch—standard deviation (centi-minutes).
REBUN	Percent of single bunches needing rebunching before hauling. NOTE: Must be three digits in terms of thousandths.
ROAD	Skid distance along road/track (feet).
SDIST	Total skid distance (feet).
SKADD	Number of feller/buncher bunches collected into this skid load.
SKBRK	Skidder time on break (centi-minutes).
SKBUN	Total bunches skidded.
SKGPH	Skidder fuel consumption (gallons/hour).
SKHR	Total skidder time on job (hours x 100).
SKLND	Skidder time spent at landing (centi-minutes).
SNLN	Skidder time at landing—nonproductive.
SKTIM	Total skidder time—all machines (centi-minutes).
SKTRE	Total number of trees skidded.
SKVOL	Total volume skidded—all machines.
SPEED	Skidder travel speed on road/track (feet/minutes).
TRPAC	Trees per acre.

VANCY	Van capacity (cubic feet x 100).
VNCON	Van contents (cubic feet x 100).
VNWT1	Time needed to replace full van with empty van—mean (centi-minutes).
VNWT2	Time needed to replace van—standard deviation (centi-minutes).
WBTU	Btu's in wood per ton.
WDIST	Total distance skidders have traveled through the woods (feet).
WDTIM	Skid time in the woods (centi-minutes).
WKDAY	Length of workday (hours).

SWITCHES

CBRK	Set by chipper to tell skidders that chipper is on break.
CHIPR	Set by chipper to indicate it is on the job.
COFFE	Set by timer to indicate coffee break time.
DAY	Set by timer to indicate start of shift.
EVCPR	Set by vans to indicate empty van available.
LUNCH	Set by timer to indicate lunch time.

TABLES

BNDIA	Total sum of diameter of skid bunch (inches).
BNTRE	Number of trees per skid bunch.
BNVOL	Volume of skidder loads (cubic feet x 100).
CPTIM	Time to chip each load (centi-minutes).
CPVOL	Volume in each chip load (cubic feet x 100).
SKILN	Time skidder is at landing on each trip (centi-minutes).
WDTIM	Time skidder is in woods on each trip (centi-minutes).

BOOLEAN VARIABLES

ADD	Conditions under which the skidder will add another bunch before skidding to chipper.
DROP	Allows skidder to drop trees if there is room at chipper or if chipper is done for the day.

VARIABLES

ALIGN	Time needed for skidder to align bunch if needed (centi-minutes).
BREAK	Time between breaks (centi-minutes).
BUCK	Total delay due to bucking logs (centi-minutes).
CHIP	Time to chip this load (centi-minutes).
CHSAW	Time needed to buck a log (centi-minutes).
CLSVN	Time to close full van (centi-minutes).
CNPVN	Chipper nonproductive time spent waiting for vans (centi-minutes).
CNPWD	Chipper nonproductive time waiting for wood (centi-minutes).
CPBRK	Time chipper spends on break (centi-minutes).
CPHR	Total chipper time (hours x 100).
DROP	Time for skidder to drop bunch (centi-minutes).
GRAPL	Skidder-grapple time per bunch (centi-minutes).
NGRAP	Number of trees the chipper-grapple takes each load.
NIGHT	Remainder of 24 hours after work shift (centi-minutes).
NTBUN	Number of trees feller/buncher left in each bunch.
RDIST	Skid road/track distance (feet).
REBUN	Time needed to rebunch skid load (centi-minutes).
RTRAV	Skidder travel time along skid road (centi-minutes).
SKBRK	Time skidders spend on break (centi-minutes).
SKHR	Total skidder time—all machines (hours x 100).
SKNLN	Total nonproductive time for skidders at landing (centi-minutes).
SKTIM	Total skid time—all machines (centi-minutes).
TVOL	Volume of each tree in terms of d.b.h. (cubic feet x 100).
VNWAT	Time needed to change vans (centi-minutes).
WDIST	Distance from skid road/trail to bunches (feet).
WKDAY	Length of work shift (centi-minutes).
WTRAV	Skidder travel time through woods (centi-minutes).

APPENDIX B

PROGRAM LISTING

```
@MTU*GPSSX8.GPSSX8,S ,TPF$.SKDCHP
GPSSX8 V2.6 RL72-8 06/26/81 08:49:39
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*    SKIDDER CHIPPER SYSTEM SIMULATION      DOCUMENTED 81
*
*      U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
*      MARKETING PROJECT, DULUTH, MINNESOTA
*      ENGINEERING PROJECT, HOUGHTON, MICHIGAN
*
*   AUTHORS:    DENNIS P. BRADLEY
*               SHARON A. WINSAUER
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*     GENERAL FUNCTIONS NEEDED IN MODEL
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
* * *  FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
*      NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
*
*      NOTE: TO AVOID DATA LOSS FROM INTEGERIZATION,
*      VALUES HAVE BEEN MULTIPLIED BY 10.
*
*      USE MEAN + ST. DEV*FN$SNORM/10
*
*      NOTE: THE LOWER END OF THE FUNCTION HAS BEEN
*      TRUNCATED TO AVOID NEGATIVE ADVANCE BLOCKS
*      WHEN STANDARD DEVIATIONS ARE LARGE
*
SNORM FUNCTION   RN2,C20
0,-15/.0668,-15/.1151,-12/.1587,-10/.2119,-8/.2742,-6/.3446,-4
.4207,-2/.5,0/.5793,2/.6544,4/.7258,6/.7881,8/.8413,10/.8849,12
.9332,15/.9772,20/.9938,25/.9986,30/.9999,40/1.,50
*
*
```

```
 40.        /  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 42.        *
 43.        *                MASTER TIMER AND REPORT GENERATOR
 44.        *  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 45.        *
 46.        *        THIS SEGMENT CONTROLS THE START AND STOP
 47.        *        OF THE SKIDDERS AND CHIPPERS, THE
 48.        *        HOURS WORKED PER DAY, X$WKDAY, AND
 49.        *        THE NUMBER OF DAYS WORKED
 50.        *        (ARGUMENT A ON THE START CARD) .
 51.        *
 52.        *        IT ALSO CALCULATES THE OUTPUT
 53.        *        VALUES SENT TO HELP BLOCKS.
 54.        *
 55.         WKDAY VARIABLE   X$WKDAY*6000            WORKDAY IN CENTIMINUTES
 56.         NIGHT VARIABLE   (24-X$WKDAY)*6000       REST OF 24 HOURS IN CENTIMINUTES
 57.         BREAK FVARIABLE  V$WKDAY/4               TIME BETWEEN BREAKS
 58.        *
 59.    1    TIMER GENERATE   ,,,1,12
 60.    2    NXDAY SAVEVALUE  DAYS+,1                 NUMBER OF CURRENT WORKING DAY
 61.    3          LOGIC S    DAY                     TIME TO START WORK
 62.    4          ADVANCE    V$BREAK
 63.    5          LOGIC S    COFFE                   TIME FOR COFFEE BREAK
 64.    6          ADVANCE    V$BRFAK
 65.    7          LOGIC S    LUNCH                   LUNCH TIME
 66.    8          ADVANCE    V$BREAK
 67.    9          LOGIC S    COFFE                   TIME FOR TEA
 68.   10          ADVANCE    V$BREAK
 69.   11          LOGIC R    DAY                     TIME TO QUIT
 70.   12          ADVANCE    V$NIGHT
 71.        *
 72.        *
 73.        *
 74.        * * * *  HELP BLOCKS GENERATE REPORT AT END OF EACH 24 HOUR DAY
 75.        *
 76.        *
 77.        * * * * REPORT VARIABLES
 78.        *
 79.         SKTIM VARIABLE   X$WDTIM+X$SKLND         TOTAL SKIDDER TIME (CENTIMINUTES)
 80.         SKHR  VARIABLE   X$SKTIM/60              TOTAL SKIDDER TIME (HOURS)
 81.        *                                         SKIDDER NON-PRODUCTIVE TIME
 82.         SKBRK FVARIABLE  QC$SKBRK*QT$SKBRK         - ON BREAK
 83.         SKNLN FVARIABLE  QC$CPBUF*QT$CPBUF         - AT LANDING
 84.        *
 85.        *
 86.   13          SAVEVALUE  SKTIM,V$SKTIM
 87.   14          SAVEVALUE  SKHR,V$SKHR
 88.   15          SAVEVALUE  SKBRK,V$SKBRK
 89.   16          SAVEVALUE  SKNLN,V$SKNLN
 90.        *
 91.        *
 92.         CPHR  FVARIABLE  X$CPTIM/60              TOTAL CHIPPER HOURS
 93.        *                                         CHIPPER NON-PRODUCTIVE TIME
 94.         CPBRK FVARIABLE  QC$CPBRK*QT$CPBRK         - ON BREAK
 95.         BUCK  FVARIABLE  QC$CHSAW*QT$CHSAW         - WAITING FOR BUCKING
 96.         CNPWD FVARIABLE  QC$BFEMT*QT$BFEMT         - WAITING FOR WOOD
 97.         CNPVN FVARIABLE  QC$EVCPR*QT$EVCPR         - WAITING FOR VANS
 98.        *
 99.   17          SAVEVALUE  CPHR,V$CPHR
100.   18          SAVEVALUE  CPBRK,V$CPBRK
101.   19          SAVEVALUE  BUCK,V$BUCK
102.   20          SAVEVALUE  CNPWD,V$CNPWD
103.   21          SAVEVALUE  CNPVN,V$CNPVN
```

```
    /
    * * * *  STAND DATA AND MACHINE CHARACTERISTICS REPORT
    *
    *              VOL/ACRE, AVE DBH, TREE HT, TREES/ACRE
22         HELP       SLSYS,X$AVVOL,X$AVDBH,X$AVHGT,X$TRPAC
    *
    *        NUMBER OF FB, FB TYPE
23         HELP       SLSYS,X$NUMFB,X$FBTYP
    *
    *        MAX BUNCH SIZE, NUM OF SKID, CHIPPER LOAD MAX
24         HELP       SLSYS,X$MXSKD,X$NUMSK,X$CMAX
    *
    *        BTU/TON WOOD, WOOD DENSITY, FB FUEL USAGE GAL/TON, FUEL BTU
25         HELP       SLSYS,X$WBTU,X$LBCFT,X$FBGPT,X$FBTU
    *
    *        SKIDDER HOURS, SKIDDER GALLONS/HOUR, SKIDDED VOLUME
26         HELP       SLSYS,X$SKHR,X$SKGPH,X$SKVOL
    *
    *        CHIPPER HOURS, CHIPPER GALLONS/HOUR, CHIPPED VOLUME
27         HELP       SLSYS,X$CPHR,X$CPGPH,X$CPVOL
    *
    *
    * * * *  SKIDDER PRODUCTION REPORT
    *
    *        SKIDDER HOURS, NUMBER OF SKIDDERS, BUNCHES SKIDDED, TREES SKIDDED
28         HELP       SKIDR,X$SKHR,X$NUMSK,X$SKBUN,X$SKTRE
    *
    *        VOLUME SKIDDED, TOTAL # OF FB BUNCHES, TOTAL SKID DISTANCE
29         HELP       SKIDR,X$SKVOL,X$SKADD,X$SDIST
    *
    *        WOODS TIME, LANDING TIME, NON-PRODUCTIVE LANDING TIME,BREAK TIME
30         HELP       SKIDR,X$WDTIM,X$SKLND,X$SKNLN,X$SKBRK
    *
    *        POUNDS/CUFT OF WOOD, SKIDDER GALLONS/HOUR
31         HELP       SKIDR,X$LBCFT,X$SKGPH
    *
    *
    * * * *  CHIPPER PRODUCTION REPORT
    *
    *        CHIPPER HOURS WORKED, POUNDS/CUFT OF WOOD, NON-PRODUCTIVE TIME
    *        WAITING FOR WOOD, NON-PRODUCTIVE TIME WAITING FOR VANS,
    *        CHIPPER GALLONS/HOUR
32         HELP       CHIPR,X$CPHR,X$LBCFT,X$CNPWD,X$CNPVN,X$CPGPH
    *
    *        TREES CHIPPED, VOLUME CHIPPED, NUMBER OF FULL VANS, NUMBER OF
    *        CHIPPER LOADS, BUCKING TIME, BREAK TIME
33         HELP       CHIPR,X$CPTRE,X$CPVOL,X$CPVNS,X$CPLOD,X$BUCK
34         HELP       CHIPR,X$CPBRK
    *
    *
35         SPLIT      1,NXDAY
    *
36   OUTPT TERMINATE  1
```

```
       /
       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
       *
       * * * SKIDDER SEGMENT * * *
       *
       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
       *
       *    THIS SEGMENT MODELS GRAPPLE TYPE SKIDDER(S)
       *    SKIDDING BUNCHES PREVIOUSLY LAID DOWN BY A FELLER BUNCHER.
       *    THE SKIDDER TRAVELS ALONG A SKID ROAD/TRAIL TO THE WOODS,
       *    THEN TRAVELS THROUGH THE WOODS TO GRAPPLE A BUNCH.
       *    IT CAN COLLECT MULTIPLE FB BUNCHES BEFORE RETURNING TO
       *    THE LANDING.
       *
       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
       *
       *
       * * * PARAMETER DEFINITIONS
       *
       *    P1
       *    P2    CLOCK TIME
       *    P3    TOTAL NO OF TREES IN BUNCH
       *    P4    TOTAL DBH OF BUNCHES COMBINED
       *    P5    TOTAL VOL OF BUNCHES COMBINED
       *    P6    NUMBER OF BUNCHES GRAPPLED
       *    P7    ROAD DISTANCE
       *    P8    WOOD DISTANCE
       *    P9    NUMBER OF TREES IN NEXT BUNCH
       *    P10   COUNTER
       *    P11   SUM OF DIA OF NEXT BUNCH
       *    P12   TOT VOL OF NEXT BUNCH
       *
       *
       * * * DEFINING VARIABLES FOR SKIDDERS
       *
       DROP  BVARIABLE  X$NTBUF'LE'X$BUFLM+LR$CHIPR
       *                                             TRUE IF ROOM TO DROP TREES
       *                                             OR CHIPPER HAS QUIT
       *
       * * * GENERATE SKIDDERS
       *
 37    SKDDR GENERATE   ,,,X$NUMSK,8,12
       *
       *     TIME TO WORK? IF NOT, WAIT
       *
 38    START GATE LS    CHIPR                        WAIT UNTIL CHIPPER IS WORKING
 39          MARK       2
 40          ASSIGN     7,V$RDIST                    ROAD DISTANCE
 41          QUEUE      RDIST
 42          ADVANCE    V$RTRAV                      TRAVEL TO WOODS
 43          DEPART     RDIST
 44          SAVEVALUE  SDIST+,P7                    TOTAL DISTANCE TRAVELED
 45          SAVEVALUE  RDIST+,P7                    TOTAL ROAD DISTANCE
       *
       *     SKIDDER IN WOODS   DETERMINE CHARACTERISTICS OF BUNCH
       *
 46    WOODS ASSIGN     9,V$NTBUN                    NUMBER OF TREES IN NEXT BUNCH
 47          ASSIGN     10,P9
 48          ASSIGN     8,V$WDIST                    WOODS DISTANCE TO BUNCH
       *
 49    NDBH  SAVEVALUE  DBH,FN$DBH                   FIND SUM OF DIAMETER AND
 50          ASSIGN     11+,X$DBH                    TOTAL VOLUME OF NEXT BUNCH
 51          ASSIGN     12+,V$TVOL
 52          LOOP       10,NDBH
```

```
     /     ADD ON FB BUNCH
     *
53          ASSIGN    3+,P9
54          ASSIGN    4+,P11
55          ASSIGN    5+,P12
56          ASSIGN    6+,1
     *
57          ASSIGN    9,0
58          ASSIGN    11,0
59          ASSIGN    12,0
     *
     *      TRAVEL TO BUNCH AND GRAPPLE IT
     *
60          QUEUE     WTRAV
61          ADVANCE   V$WTRAV
62          DEPART    WTRAV
63          SAVEVALUE SDIST+,P8
64          SAVEVALUE WDIST+,P8
     *
     *      IF NECESSARY - ALIGN BUNCH
     *
65          TRANSFER  .X$ALIGN,GRAPL,ALIGN
     *
66    ALIGN QUEUE     ALIGN
67          ADVANCE   V$ALIGN
68          DEPART    ALIGN
     *
     *      GRAPPLE BUNCH
     *
69    GRAPL QUEUE     GRAPL
70          ADVANCE   V$GRAPL
71          DEPART    GRAPL
     *
     *      TRAVEL TO COLLECTION POINT (ROAD) DIST = P8
     *
72          QUEUE     WTRAV
73          ADVANCE   V$WTRAV
74          DEPART    WTRAV
75          SAVEVALUE SDIST+,P8
76          SAVEVALUE WDIST+,P8
     *
     *      SHOULD SKIDDER TAKE ANOTHER BUNCH? IS SO RETURN TO WOODS
77          TEST NE   BV$ADD,1,WOODS          IF BV$ADD=1 RETURN FOR A BNCH
     *
78          TEST LE   P6,1,REBUN      MUST REBUNCH IF MORE THAN ONE BUNCH
     *
     *      DOES  SKIDDER NEED TO REBUNCH
     *
     *
79          TRANSFER  .X$REBUN,SKLND,REBUN
     *
80    REBUN QUEUE     REBUN                   DROP TREES AND REBUNCH
81          ADVANCE   V$REBUN
82          DEPART    REBUN
```

```
         /
         *      SKID TO LANDING
         *
 83      SKLND QUEUE      RDIST
 84            ADVANCE    V$RTRAV
 85            DEPART     RDIST
 86            SAVEVALUE  SDIST+,P7
 87            SAVEVALUE  RDIST+,P7
         *
         *     TABULATE  WOODS TIME
         *
 88            SAVEVALUE  WDTIM+,MP2
         *
         *     TABULATE DATA ON BUNCH
 89            TABULATE   WDTIM
 90            TABULATE   BNTRE
 91            TABULATE   BNVOL
 92            TABULATE   BNDIA
         *
         *
         *    SKIDDER AT LANDING
         *    SKIDDER MUST EITHER DROP LOAD, WAIT FOR ROOM AT CHIPPER TO DROP
         *    LOAD OR QUIT FOR THE DAY
         *
 93      LAND  MARK       2                            KEEP TRACK OF LANDING TIME
 94            GATE LS    CBRK,SWORK                   IF CHIPPER IS ON BREAK
 95            QUEUE      SKBRK                        SKIDDERS CAN
 96            GATE LR    CBRK                         TAKE BREAK
 97            DEPART     SKBRK
         *
 98      SWORK QUEUE      CPBUF
 99            TEST E     BV$DROP,1                    WAIT FOR ROOM TO DROP TREES OR
         *                                             DROP IF CHIPPER HAS QUIT
100            SEIZE      CPBUF
101            DEPART     CPBUF
102            ADVANCE    V$DROP
103            SAVEVALUE  NTBUF+,P3              ADD THIS LOAD TO CHIPPER BUFFER
104            RELEASE    CPBUF
         *
105            SAVEVALUE  SKLND+,MP2                   SKIDDER TIME AT LANDING
         *
         *     TABULATE DATA ON BUNCH
106            TABULATE   SKTLN
107            SAVEVALUE  SKTRE+,P3
108            SAVEVALUE  SKVOL+,P5
109            SAVEVALUE  SKBUN+,1
110            SAVEVALUE  SKADD+,P6
         *
         *
111            ASSIGN     3,0
112            ASSIGN     4,0
113            ASSIGN     5,0
114            ASSIGN     6,0
115            ASSIGN     7,0
116            ASSIGN     8,0
         *
         *
117      WAIT  TRANSFER   ,START
```

```
        /
        * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
        *
        *  *  *  CHIPPER SEGMENT  *  *  *
        *
        *      THIS SEGMENT MODELS A CHIPPER WITH A SELF LOADING GRAPPLE
        *
        * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
        *
        *
        *                    PARAMETER DEFINITIONS
        *
        *      P1            CLOCK TIME
        *      P2            NUMBER OF TREES IN CHIP-GRAPPLE LOAD
        *      P3            VOL OF CHIP-GRAPPLE LOAD
        *      P4            SUM OF DIA OF CHIP-GRAPPLE LOAD
        *      P5            LOOP COUNTER
        *
        *
 118    CHIPR GENERATE   ,,,1,,6,6
 119          LOGIC S    EVCPR                  START WITH A VAN READY
        *
 120    CSTRT GATE LS    DAY                    TIME TO START WORK ?
 121          LOGIC S    CHIPR                    CHIPPER IS WORKING
 122    NEWLD MARK       1
 123          QUEUE      EVCPR
 124          GATE LS    EVCPR                  SEE IF THERE IS A VAN AVAILABLE
 125          DEPART     EVCPR
        *
 126          QUEUE      BFEMT
 127          TEST G     XSNTBUF,0              ARE THERE TREES TO CHIP ?
 128          DEPART     BFEMT
 129          ASSIGN     2,V$NGRAP              NUMBER OF TREES TO GRAPPLE
 130          TEST L     X$NTBUF,P2,GRAPE       IF GRAPPLE CAN NOT TAKE FULL LOAD
        *                                       TAKE THOSE AVAILABLE
 131          ASSIGN     2,X$NTBUF
        *
        *     GRAPPLE TREES AND DEFINE SIZE AND VOL
        *
 132    GRAPE ASSIGN     5,P2
 133    LOAD  SAVEVALUE  DBH,FN$DIAM
 134          ASSIGN     4+,X$DBH
 135          ASSIGN     3+,V$TVOL
 136          LOOP       5,LOAD
        *
        *     REMOVE THESE TREES FROM BUFFER AREA AND RESTART SCAN SO WAITING
        *     SKIDDERS CAN DROP WOOD
        *
 137          SAVEVALUE  NTBUF-,P2
 138          BUFFER
        *
        *     X$PDELY - % OF THE TIME THERE IS A DELAY AT THE CHIPPER FOR CHAIN-SAW
        *     OPERATION
        *
 139          TRANSFER   ,X$PDELY,CHIP,CHSAW
        *
 140    CHSAW QUEUE      CHSAW
 141          ADVANCE    V$CHSAW                CHAINSAW DELAY
 142          DEPART     CHSAW
        *
 143    CHIP  QUEUE      CHIP
 144          ADVANCE    V$CHIP                 CHIP LOAD
 145          DEPART     CHIP
        *
```

```
                  /        RECORD STATISTICS OF CHIPPING
                  *
       146                 SAVEVALUE  CPTIM+,MP1
       147                 TABULATE   CPVOL
       148                 TABULATE   CPTIM
       149                 SAVEVALUE  CPLOD+,1
       150                 SAVEVALUE  CPTRE+,P2
       151                 SAVEVALUE  CPVOL+,P3
                  *
                  *        ADD CHIPPED VOL TO VAN
                  *
       152                 SAVEVALUE  VNCON+,P3
       153                 ASSIGN     2,0
       154                 ASSIGN     3,0
       155                 ASSIGN     4,0
                  *
                  *        SEE IF THE VAN IS FULL
                  *
       156                 TEST GE    XSVNCON,XSVANCY,NEWLD   VAN NOT FULL GET NEW LOAD
                  *
                  *        VAN IS FULL - ONE TRANSACTION GOES TO CLOSE VAN AND
                  *        LINKS IT ON FULL VAN CHAIN TO BE HAULED
                  *
                  *        THE PARENT TRANSACTION REMAINS THE CHIPPER
                  *
       157                 LOGIC R    EVCPR
       158          FULVN  SPLIT      1,LNKVN
       159                 MARK       1
       160                 QUEUE      CPBRK                       CHECK FOR BREAK TIME
                  *
       161                 GATE LS    COFFE,NOBRK
       162                 LOGIC S    CBRK
       163                 ADVANCE    1500                        TAKE BREAK
       164                 LOGIC R    COFFE
       165                 LOGIC R    CBRK
       166          NOBRK  GATE LS    LUNCH,CDONE
       167                 LOGIC S    CBRK
       168                 ADVANCE    3000                        STOP FOR LUNCH
       169                 LOGIC R    LUNCH
       170                 LOGIC R    CBRK
                  *
       171          CDONE  DEPART     CPBRK                       IS IT END OF SHIFT?
       172                 SAVEVALUE  CPTIM+,MP1
       173                 GATE LR    DAY,NEWLD                   IF NOT END OF DAY GET NEW LOAD
       174                 LOGIC R    CHIPR                       CHIPPER DONE FOR TODAY
       175                 TRANSFER   ,CSTRT
                  *
       176          LNKVN  SAVEVALUE  VNCON,0
       177                 SAVEVALUE  CPVNS+,1
       178                 ADVANCE    V$CLSVN                    CLOSE THE VAN
       179                 ADVANCE    V$VNWAT                    BRING IN ANOTHER VAN
       180                 LOGIC S    EVCPR
       181                 TERMINATE
                  *
                  *
```

```
/
*    *    *   TABLE DEFINITIONS    *    *    *
*
 WDTIM TABLE      MP2,0,50,20              SKIDDER TIME IN WOODS
 SKTLN TABLE      MP2,0,25,20              SKIDDER TIME AT LANDING
*
 BNTRE TABLE      P3,0,2,20                NO. OF TREES PER SKIDDER LOAD
 BNVOL TABLE      P5,0,500,40              VOLUME PER SKID LOAD
 BNDIA TABLE      P4,0,10,30               SUM OF DIAMETER/SKIDDER LOAD
*
 CPVOL TABLE      P3,0,200,30              VOLUME PER CHIPPER LOAD
 CPTIM TABLE      MP1,0,20,30              TIME PER CHIPPER LOAD
*
*
*  *  *  FUNCTION AND VARIABLE DEFINITIONS  *  *  *
*
* * * DEFINING VARIABLES FOR STAND
*
 NTBUN FVARIABLE  FNSNTBUN
 TVOL  FVARIABLE  (133*X$DBH*X$DBH-283)/10  TREE VOL IN TERMS OF DIA
 RDIST FVARIABLE  X$ROAD                   ROAD DISTANCE
 WDIST FVARIABLE  FN$WDIST                 WOODS DISTANCE
*
* * * DEFINING VARIABLES FOR SKIDDER
*
 ADD   BVARIABLE  P4'L'X$HALF              IF LESS THAN 1/2 LOAD ADD MORE
 RTRAV FVARIABLE  P7*100/X$SPEED           TRAVEL TIME ON ROAD
 WTRAV FVARIABLE  P8*150/X$SPEED           TRAVEL IN WOODS 2/3 ROAD SPEED
 GRAPL FVARIABLE  X$GRPL1+X$GRPL2*FN$SNORM/10     TIME TO GRAPPLE
 ALIGN FVARIABLE  X$ALGN1+X$ALGN2*FN$SNORM/10     ALIGN BUNCH
 REBUN FVARIABLE  X$REBN1+X$REBN2*FN$SNORM/10
 DROP  FVARIABLE  X$DROP1+X$DROP2*FN$SNORM/10     TIME TO DROP BUNCH
*
* * * *  DEFINING VARIABLES FOR CHIPPER/LOADER
*
 NGRAP FVARIABLE  FN$NGRAP
 CHIP  FVARIABLE  P2*10                            CHIP TIME IN CENTIMIN
 CHSAW FVARIABLE  X$CHSW1+X$CHSW2*FN$SNORM/10
 VNWAT FVARIABLE  X$VNWT1+X$VNWT2*FN$SNORM/10      VAN WAIT TIME
 CLSVN FVARIABLE  X$CLSV1+X$CLSV2*FN$SNORM/10    TIME TO CLOSE VAN
*
*
* * * STAND FUNCTIONS
 NTBUN FUNCTION   RN3,D24                  NUMBER OF TREES PER BUNCH
.004,2/.025,3/.06,4/.09,5/.15,6/.20,7/.24,8/.30,9/.35,10/.39,11/.45,12
.52,13/.58,14/.61,15/.66,16/.70,17/.73,18/.76,19/.80,20/.84,21/.87,22
.91,23/.95,24/1.0,25
*
 WDIST FUNCTION   RN3,C14                  WOODS DISTANCE FOR SKIDDER
.0,0/.23,5/.35,10/.42,15/.53,20/.63,25/.72,30/.77,35/.79,40/.82,45
.86,50/.88,55/.90,60/1.00,100
*
* * * SKIDDER FUNCTIONS
 DBH    FUNCTION  RN4,D7                   TREE DIAMETER INCHES
.05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
```

```
/
* * * CHIPPER FUNCTIONS
*
 DIAM  FUNCTION   RN5,D7                  TREE DIAMETER FOR CHIPPING
.05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
*
 NGRAP FUNCTION   RN3,D10                 GRAPPLE LOAD FOR CHIPPER
.12,1/.31,2/.49,3/.66,4/.81,5/.89,6/.95,7/.98,8/.99,10/1.00,12
*
*
*   *   *   INITIAL VALUES FOR THIS RUN   *   *   *
*
       INITIAL    X$WKDAY,8               HRS  IN WKDAY
*
       INITIAL    X$AVHGT,43/X$AVDBH,550  STAND DATA
       INITIAL    X$AVVOL,345000
       INITIAL    X$TRPAC,844
       INITIAL    X$ROAD,300              AVE ONE-WAY DISTANCE
       INITIAL    X$LBCFT,65              LB OF  WOOD /CU  FT
       INITIAL    X$WBTU,8000000          BTU   PER TON  OF  WOOD
       INITIAL    X$FBTU,150000           BTU  IN  FUEL PER GAL
*
       INITIAL    X$FBTYP,0/X$NUMFB,1     TRACKED TYPE FELLER BUNCHER
       INITIAL    X$FBGPT,33              FELLER BUNCHER GAL/TON * 100
*
       INITIAL    X$NUMSK,1                       NUMBER OF SKIDDERS
       INITIAL    X$MXSKD,150/X$HALF,85   MAX SKID BUNCH SUM OF DIA
       INITIAL    X$SKGPH,400                     GAL/HRX100
       INITIAL    X$SPEED,352             SKID TRAVEL SPEED FT/MIN
       INITIAL    X$GRPL1,65/X$GRPL2,20           TIME TO POSITION & GRAPPLE
       INITIAL    X$ALGN1,50/X$ALGN2,30   TIME TO ALIGN BUNCH
       INITIAL    X$ALIGN,010                     % OF BUNCHES TO BE ALIGNED
       INITIAL    X$DROP1,30/X$DROP2,15           TIME TO DROP BUNCH
       INITIAL    X$REBN1,50/X$REBN2,25   TIME TO REBUNCH
       INITIAL    X$REBUN,150                     % OF TIME HE REBUNCHES 1 LOAD
*
       INITIAL    X$BUFLM,50       LIMIT - TREES AT CHIPPER
*
       INITIAL    X$CMAX,12               MAX CHIPPER LOAD
       INITIAL    X$CPGPH,570             LARGE CHIPPER GAL/HR.
       INITIAL    X$CHSW1,47/X$CHSW2,9    CHAIN SAW DELAY TIME
       INITIAL    X$PDELY,050
*
       INITIAL    X$VANCY,100000
       INITIAL    X$CLSV1,100                     CLOSE VAN TIME
       INITIAL    X$VNWT1,400                     VAN WAIT TIME
*
       RMULT      ,,,17,17
       START      5,,5,1
       END
```

```
      SUBROUTINE SLSYS(IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL MXSKD
C
    1 FORMAT(1H1,54X,'SAWLOG  SORTING  '
     A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
     B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
     CT.  OF  AGRICULTURE'/1H ,29X, 'FOREST  PRODUCTS  MARKETING  AND  U
     DTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H,40
     EX,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H ,62X,
     F'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
     GA. WINSAUER, PROGRAMMER'/)
C
    2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.',/
     A                                 1H0,F12.2,' CUFT., AVERAGE VOLUME',
     B' PER ACRE.'/1H0,F12.2,' INCHES, AVERAGE DBH.'/1H0,F12.2,' FEET,',
     C' AVERAGE TREE HEIGHT.'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
     D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
C
    3 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'TRACKED TYPE')
C
    4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'RUBBER-TIRED TYPE',//)
C
C
    8 FORMAT(
     A /1H0,'  B.  SKIDDERS.',10X  ,I10,'  MACHINE(S)',5X,'RUBBER',
     A'-TIRED GRAPPLE SKIDDER(S). ',//)
C
    9 FORMAT(1H,8X,'MAXIMUM SKID BUNCH HAS TOTAL SUM OF '
     A'DIAMETER',F8.2,' INCHES'//)
C
   11 FORMAT(1H0,'  C.  CHIPPER-LOADER.',//1H,8X,'THE LOADER',
     A' CAN TAKE A LOAD OF ',F5.0,'TREES')
C
C
   13 FORMAT(1H,6X,'ENERGY BALANCE',//,12X,F6.2,' GAL/TON - ',
     A'FELLER BUNCHER',//,12X,F6.2,' GAL/TON - SKIDDER',//,
     B12X,F6.2,' GAL/TON - CHIPPER',//,11X,F7.2,' TOTAL GAL/TON ',
     C'@',F10.2,' BTU/GAL',///)
C
   14 FORMAT(1H,7X,F10.2,' BTU/TON USED AS FUEL',//,8X,F10.2,
     A' BTU/TON HARVESTED FROM WOOD',///,
     B9X,F9.2,5X,'ENERGY BENEFIT RATIO.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I + 1
      IF ( I .GT. 6 ) I = 1
      GO TO (10,20,30,40,50,60),I
C
   10 CONTINUE
      AVVOL= X1/100.
C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
      AVDBH= X2/100.
C AVDBH = AVERAGE DBH - INCHES
      AVHGT=X3
C AVHGT = AVERAGE TREE HEIGTH - FEET
      TRPAC= X4
C TRPAC = AVERAGE NUMBER TREES PER ACRE
      TRSPC=(43560./TRPAC)**.5
C TRSPC = AVERAGE TREE SPACING - FEET
      WRITE (6,1)
      WRITE(6,2)AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
      RETURN
```

```
C
   20 CONTINUE
      NUMFB=X1
C NUMFB = NUMBER OF FELLER-BUNCHERS
      FBTYP=X2
C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
      IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
      IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
      RETURN
C
   30 CONTINUE
      MXSKD  = X1
C   MXSKD    MAXIMUM SUM OF DIAMETER PER BUNCH
      NUMSK=X2
C NUMSK = NUMBER OF SKIDDERS
      WRITE(6,8) NUMSK
      WRITE(6,9) MXSKD
      XLODLM = X3
C  CHIPPER LOAD LIMIT
      WRITE(6,11)XLODLM
      RETURN
C
   40 CONTINUE
      WBTU=X1
C  BTU PER TON OF WOOD
      XDEN=X2
C  LBS OF WOOD PER CU. FT.
      FBGPT = X3/100
      FBTU=X4
      RETURN
C
   50 CONTINUE
C  HOURS SKIDDER WORKED
      SKHR = X1/100.
      SKGPH = X2/100
C  SKIDDER FUEL CONSUMPTION - GAL/HOUR
      SKTNS = X3*XDEN/200000
C  SKIDDER PRODUCTION IN TONS
      RETURN
C
   60 CONTINUE
      CPHR = X1/100.
C  HOURS CHIPPER WORKED
      CPGPH = X2/100
C  CHIPPER FUEL CONSUMPTION - GAL/HOUR
      CPTNS = X3*XDEN/200000
C  CHIPPER PRODUCTION IN TONS
C  CALCULATE TOTAL FUEL CONSUMPTION
      SKTFC = SKHR * SKGPH
      CPTFC = CPHR * CPGPH
      SKGPT = SKTFC/SKTNS
      CPGPT = CPTFC/CPTNS
      TGPT = FBGPT+SKGPT+CPGPT
      TONS = SKTNS
C  TOTAL TONS COMPLETE
C  CHANGE TO CPIR TONS WHEN ADDED
      FBTFC = FBGPT*TONS
      SKTFC = SKGPT*TONS
      CPTFC = CPGPT*TONS
      TFC = FBTFC+SKTFC+CPTFC
C  CALCULATE GALLONS OF FUEL PER TON
C BTU PER TON USED AS FUEL
      BTUTF = TGPT * FBTU
C  ENERTY BENEDIT RATIO
      EBC = WBTU/BTUTF
C
C
      WRITE(6,13)FBGPT,SKGPT,CPGPT,TGPT
C
      WRITE(6,14)BTUTF,WBTU,EBC
      RETURN
      END
      SUBROUTINE SKIDR (IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL  SKTNS
      INTEGER SKDIS,SKBUN,SKTRE
C
C
    1 FORMAT(1H1,9X,'S K I D D I N G   P R O D U C T I O N   A N D',
     A'   C O S T   S U M M A R Y  '//////,1H,132('*'),//,1H,'I.      A.',
     BF8.2,5X,'HOURS WORKED BY SKIDDER(S).',//,1H,6X,'B.',I5,8X,
     C'NUMBER OF SKIDDER(S).',//
     D                            1H ,'II.   A.',I5,8X,'BUNCHES ',
     E'SKIDDED - ALL MACHINES.',/)
C
    2 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES',
     A' COLLECTED.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' SKIDDER BUNCH.',//,
     C7X,'B.',I5,8X,'TREES SKIDDED - ALL MACHINES.',//,7X,'C.',
     DF8.2,5X,'VOLUME SKIDDED - CU.FT. - ALL MACHINES.',//,7X,'D.',
     E  I8,5X,'TOTAL DISTANCE SKIDDED.',//,7X,'E.',
     FF8.2,5X,'TOTAL TONS SKIDDED - ALL MACHINES.',///)
C
    3 FORMAT(1H,'III.  A.',F8.2,5X,'BUNCHES SKIDDED PER MACHINE ',
     A'HOUR.',//,7X,'B.',F8.2,5X,'TREES SKIDDED PER MACHINE HOUR.',//,
     B7X,'C.',F8.2,5X,'VOL. SKIDDED PER MACHINE HOUR. - CU.FT.',
     C//,7X,'D.',F8.2,5X,'TONS SKIDDED PER MACHINE HOUR.'/)
C
    4 FORMAT(1H,'IV.   A.',F8.2,5X,'AVERAGE ONE-WAY SKID DISTANCE ',
     A'PER TRIP - FEET.',//,7X,'B.',F8.2,5X,'AVERAGE ROUND TRIP ',
     B'TIME IN MINUTES - ALL ACTIVITIES.',//,     16X,F8.2,5X,
     C            'TIME - LANDING TO WOODS AND RETURN.',//,16X,
     DF8.2,5X,'PRODUCTIVE TIME - LANDING ACTIVITY.',//,
     F    16X,F8.2,5X,'NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.',
     G  //1H ,15X,F8.2,5X,'TIME ON BREAKS'/)
C
C
    6 FORMAT(1H,'V.    A.',F8.2,5X,'TOTAL GALLONS USED.',//,16X,
     A   F8.2,5X,'GALLONS PER HOUR.',//,          16X,F8.2,5X,'GALLONS',
     B' PER TON.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
C
      I = I+ 1
      IF ( I .GT. 4) I = 1
      GO TO ( 10,20,30,40 ),I
C
   10 CONTINUE
      SKHR = X1/100.
      NUMSK = X2
C NUMSK = NUMBER OF SKIDDERS
      SKBUN = X3
C SKBUN = BUNCHES SKIDDED, ALL MACHINES
      SKTRE = X4
C SKTRE = TREES SKIDDED, ALL MACHINES
      RETURN
C
```

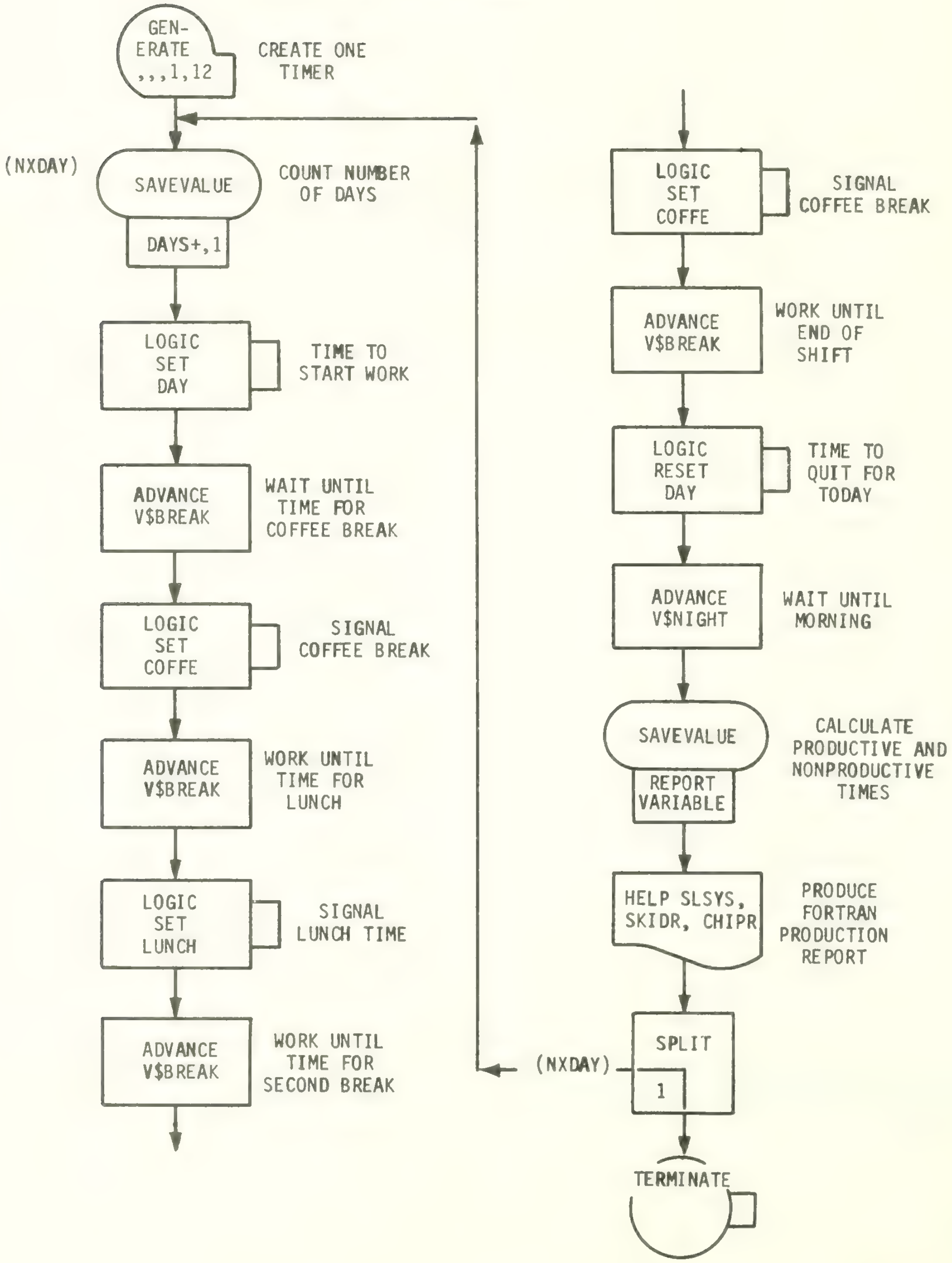
```
   20 CONTINUE
      SKVOL = X1/100.
C SKVOL = VOL. SKIDDED -CUFT. -ALL MACHINES
      BNTOT = X2
C  TOTAL NUMBER OF FELLER-BUNCHER BUNCHES.
      SKDIS = X3
C SKDIS = DISTANCE SKIDDED -FEET PER ROUND TRIP -ALL MACHINES
      BNAVE = BNTOT/SKBUN
C  BNAVE  THE AVE. # OF FELLER BUNCHER BUNCHES COLLECTED
      RETURN
C
   30 CONTINUE
      SKPWL = X1 /( 100.*SKBUN)
C SKPWL = PRODUCTIVE TIME - LANDING TO WOODS AND RETURN
      SKLND = X2/(100.*SKBUN)
      SKNLN = X3 /( 100.*SKBUN)
C SKNLN = NON-PRODUCTIVE TIME - WAITING TO DROP THE BUNCH AT THE CHIPPER
C SKBRK = TIME ON BREAKS
      SKBRK = X4/(100.*SKBUN)
      SKPLN = SKLND - SKNLN - SKBRK
      RETURN
C
   40 CONTINUE
      LBCFT = X1
C  LBCFT   POUNDS PER CUBIC FOOT OF WOOD
      SKGPH = X2/100
C  SKGPH   SKIDDER  GALLONS/HOUR
C
      SKTPB = SKTRE*1./SKBUN
C   SKTPB   TREES PER BUNCH
      WRITE(6,1)SKHR,NUMSK,SKBUN
C
      SKTNS = (SKVOL*LBCFT)/2000.
C   SKTNS   TOTAL TONS SKIDDED
       SKBMH = SKBUN/SKHR
C SKBMH = BUNCHES SKIDDED PER MACHINE HOUR
      SKTMH = SKTRE/SKHR
C SKTMH = TREES SKIDDED PER MACHINE HOUR
      WRITE(6,2)BNAVE,SKTPB,SKTRE,SKVOL,SKDIS,SKTNS
C
C
      SKVMH = SKVOL/SKHR
C SKVMH = VOL. SKIDDED PER MACHINE HOUR
      SKTNH = SKTNS/SKHR
C   SKTNH   TONS SKIDDED PER MACHINE HOUR
      SKADS = SKDIS*1./(2.*SKBUN)
C SKADS = AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET
      SKTMA = SKHR*60/SKBUN
C SKTMA = AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES
      WRITE(6,3)SKBMH,SKTMH,SKVMH,SKTNH
C
      WRITE(6,4)SKADS,SKTMA,SKPWL,SKPLN,SKNLN,SKBRK
C
C
C
      SKTGU = SKGPH*SKHR
C   SKTGU   TOTAL GALLONS USED
      SKGPT = SKTGU/SKTNS
C   SKGPT   GALLOMS PER TON
      WRITE(6,6)SKTGU,SKGPH,SKGPT
      RETURN
      END
      SUBROUTINE CHIPR (IX)
      DIMENSION IX(5)
      INTEGER      CPLOD
      INTEGER CPTRE,CPVNS
C
    1 FORMAT(1H1,9X,'C H I P P E R - L O A D E R   P R O D U C T ',
     A'I O N   A N D   C O S T   S U M M A R Y ',//,1H,132('*'),///
     B///,1H,'I.     A.',F8.2,5X,'HOURS WORKED BY CHIPPER-LOADER.',
     C                  ///,1H,'II.    A.',I5,8X,'LOADS CHIPPED.',//,1H,
     E    15X,F8.2,5X,'AVERAGE NUMBER OF STEMS PER LOAD.',//,1H,
     F 15X,F8.2,5X,'AVERAGE VOLUME PER LOAD - CU.FT.',/)
C
    2 FORMAT(1H,   6X,'B.',I8,5X,'TREES CHIPPED.',//,7X,'C.',F8.2,
     A5X,'VOLUME CHIPPED - CU.FT.',//,7X,'D.',F8.2,5X,'TONS CHIP',
     B'PED.',//,7X,'E.',I8,5X,'VANS FILLED.',//,      16X,F8.2,5X,
     C'AVERAGE NUMBER OF LOADS PER VAN.',//,     16X,F8.2,5X,
     D'AVERAGE VOLUME PER VAN - CU.FT.',//,     16X,F8.2,5X,
     E'AVERAGE TONS PER VAN.',///)
C
    3 FORMAT(1H,'III.  A.',F8.2,5X,'LOADS CHIPPED PER MACHINE HOUR.',
     A//,7X,'B.',F8.2,5X,'TREES CHIPPED PER MACHINE HOUR.',//,7X,
     B'C.',F8.2,5X,'VOLUME CHIPPED PER MACHINE HOUR - CU.FT.',//,
     C7X,'D.',F8.2,5X,'TONS CHIPPED PER MACHINE HOUR.',//,
     D7X,'E.',F8.2,5X,'VANS FILLED PER MACHINE HOUR.',///)
C
    4 FORMAT(1H,'IV.    A.',F8.2,5X,'AVERAGE CHIPPING TIME PER VAN',
     A' FILLED - ALL ACTIVITIES - MINUTES.',//,          16X,F8.2,5X,
     B'PRODUCTIVE TIME PER VAN - MINUTES.',//,          16X,F8.2,5X,
     C'NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MIN',
     D'UTES.',//,           23X,F8.2,5X,'LOADER WAITING FOR WOOD FROM',
     E' SKIDDERS - MINUTES.',//,          23X,F8.2,5X,'CHIPPER WAIT',
     F'ING FOR VANS TO FILL - MINUTES.',//1H ,22X,F8.2,5X,
     G  'BUCKING TIME'//1H ,22X,F8.2,5X,'BREAK TIME'///)
C
C
    6 FORMAT(1H,'VI.    A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED.',
     A//,          16X,F8.2,5X,'GALLONS/HOUR.',//,          16X,F8.2,
     B5X,'GALLONS/TON.')
C
        X1 = IX(1)
        X2 = IX(2)
        X3 = IX(3)
        X4 = IX(4)
        X5 = IX(5)
C
      I = I+ 1
      IF ( I .GT. 3 ) I = 1
      GO TO ( 10,20,30 ) , I
C
   10 CONTINUE
      CPHR = X1/100.
      LBCFT = X2
C   LBCFT   POUNDS OF WOOD PER CUBIC FOOT
      CNPWD = X3/100.
C CNPWD = LOADER WAITING FOR WOOD FROM SKIDDER
      CNPVN = X4/100.
C CNPVN  = CHIPPER WIATING FOR VAN FROM TRUCKS
      CPGPH = X5/100.
C   CPGPH   CHIPPER-LOADER GALLONS PER HOUR
      RETURN
```

```
C
  20 CONTINUE
      CPTRE = X1
C CPTRE = TREES CHIPPED
      CPVOL = X2/100.
C CPVOL = VOLUME CHIPPED, CUFT.
       CPVNS = X3
C CPVNS = VANS FILLED
      CPLOD = X4
C CPLOD = LOADS CHIPPED
      BUCK = X5/100
C BUCK = BUCKING TIME
      RETURN
C
  30 CONTINUE
      CPBRK = X1/100
C CPBRK = BREAK TIME
C
      CPSPL = CPTRE*1./CPLOD
C CPSPL = AVERAGE NUMBER OF STEMS PER LOAD
      CPVPL = CPVOL/CPLOD
C CPVPL = AVERAGE VOLUME PER LOAD, CUFT.
      WRITE (6 ,1)          CPHR,         CPLOD,CPSPL,CPVPL
      CPTNS = (CPVOL*LBCFT)/2000.
C   CPTNS    TOTAL TONS CHIPPED
C
      CPLPV = CPLOD*1./CPVNS
C CPLPV = AVERAGE NUMBER OF LOADS PER VAN
      CPVPV = CPVOL/CPVNS
C CPVPV = AVERAGE VOLUME PER VAN, CUFT.
      CPTPV = CPTNS/CPVNS
C   CPTPV    TONS PER VAN
      WRITE(6,2)CPTRE,CPVOL,CPTNS,CPVNS,CPLPV,CPVPV,CPTPV
C
      CPLMH = CPLOD/CPHR
C CPLMH = LOADS CHIPPED PER MACHINE HOUR
      CPTMH = CPTRE/CPHR
C CPTMH = TREES CHIPPED PER MACHINE HOUR
      CPVLH = CPVOL/CPHR
C CPVLH = VOLUME CHIPPED PER MACHINE HOUR, CUFT.
      CPVNH = CPVNS/CPHR
C CPVNH = VANS FILLED PER MACHINE HOUR
      CPTNH = CPTNS/CPHR
C   CPTNH    TONS CHIPPED PER MACHINE HOUR
      CPACT = CPHR *60/CPVNS
C CPACT = AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES -MINUTES
      WRITE(6,3)CPLMH,CPTMH,CPVLH,CPTNH,CPVNH
C
      CPNPT =(CNPWD + CNPVN + BUCK + CPBRK)/CPVNS
C CPNPT = NON PRODUCTIVE CHIPPERN TIME
      CPPTM = CPACT-CPNPT
C CPPTM = PRODUCTIVE TIME PER VAN - MINUTES
      CNPWD = CNPWD/CPVNS
      CNPVN  = CNPVN/CPVNS
      BUCK = BUCK/CPVNS
      CPBRK = CPBRK/CPVNS
      WRITE(6,4)CPACT,CPPTM,CPNPT,CNPWD,CNPVN,BUCK,CPBRK
C
C
      CPTGU = CPHR*CPGPH
C   CPTGU    TOTAL GALLONS USED
      CPGPT = CPGPH/CPTNH
C   CPGPT    GALLONS PER TON
      WRITE(6,6)CPTGU,CPGPH,CPGPT
      RETURN
      END
```

APPENDIX C
COMPLETE FLOW CHARTS

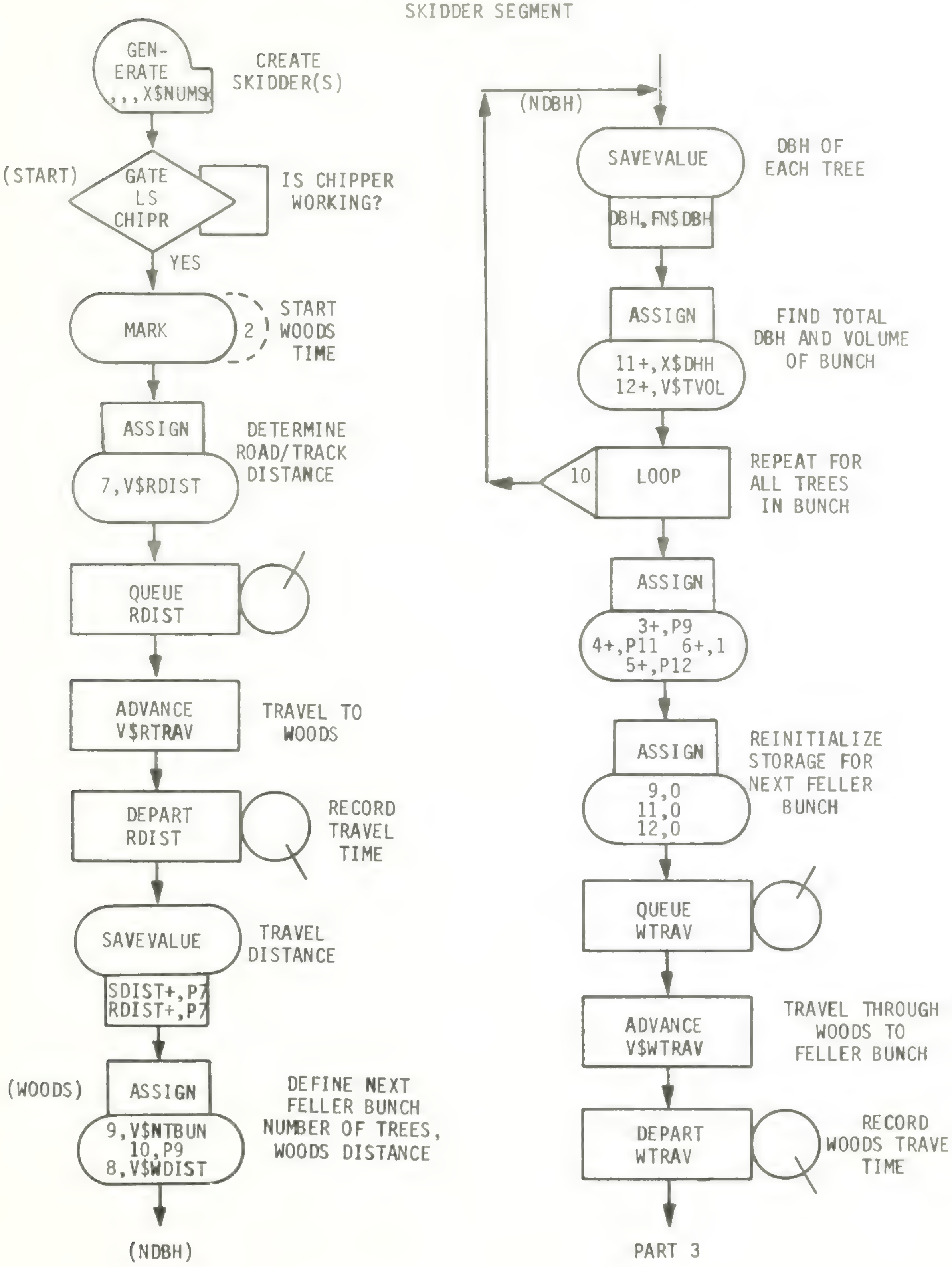
COMPLETE FLOW CHARTS - PART 1 OF 7

TIMER SEGMENT



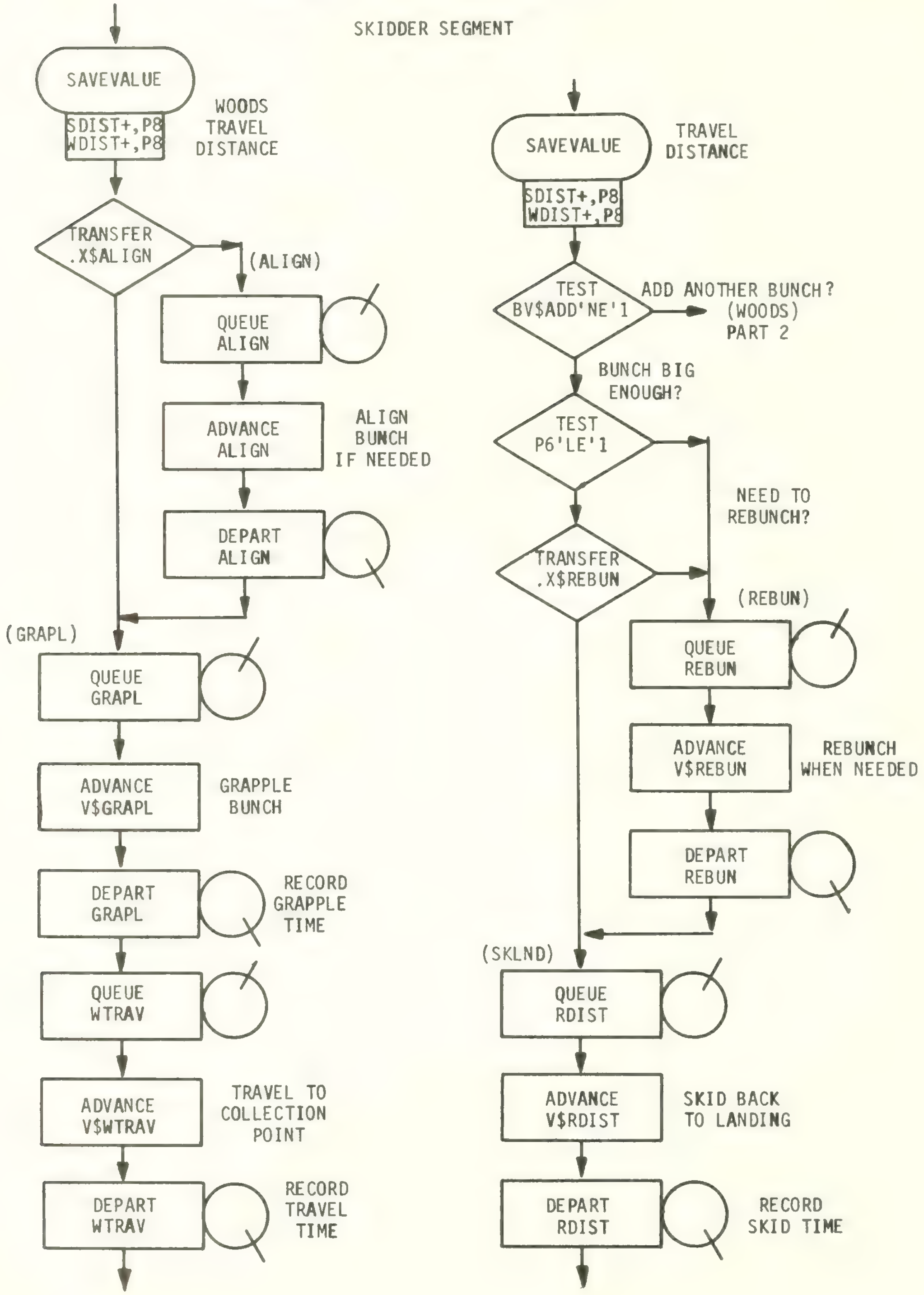
COMPLETE FLOW CHARTS - PART 2 OF 7

SKIDDER SEGMENT



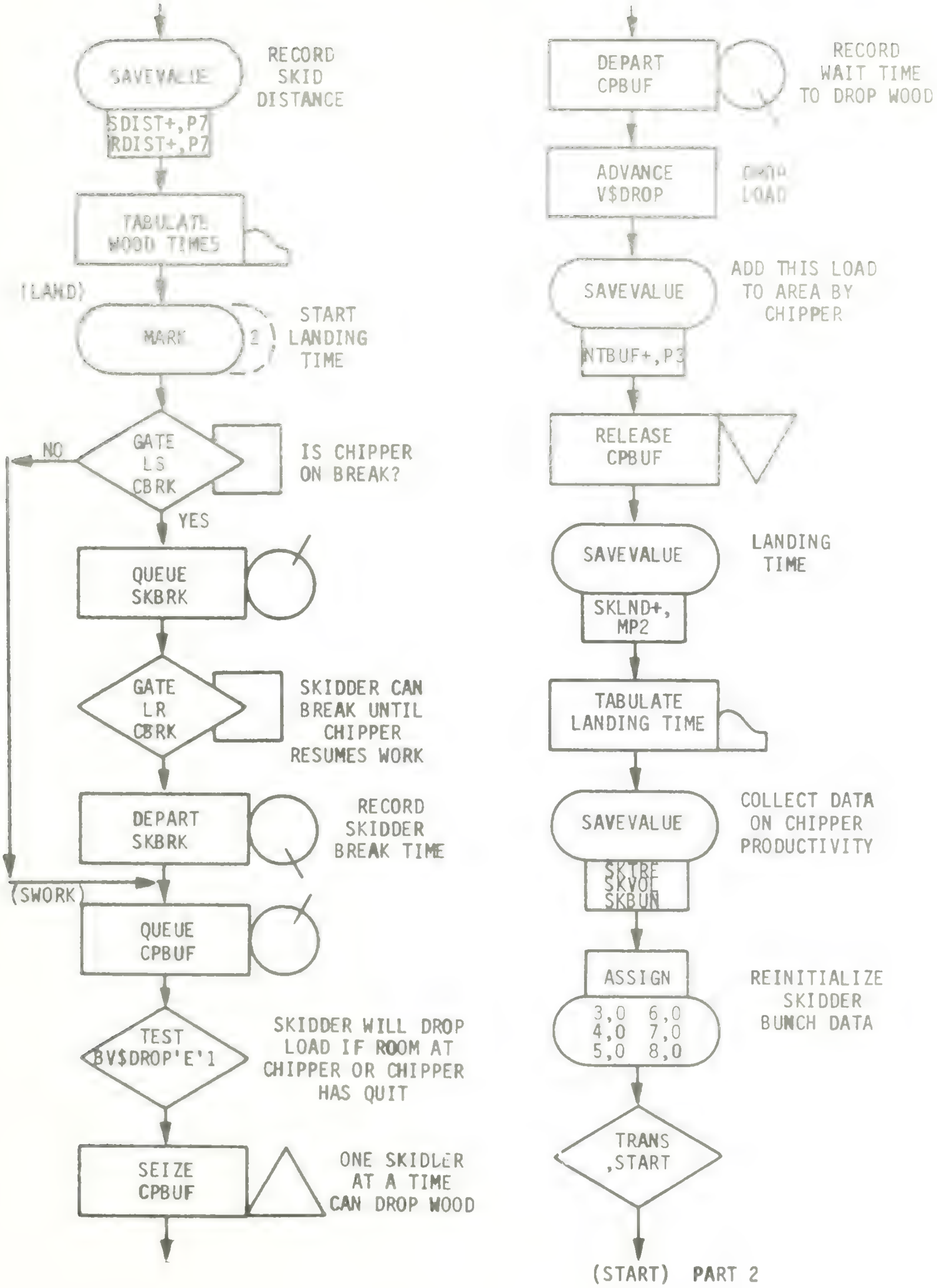
COMPLETE FLOW CHARTS - PART 3 OF 7

SKIDDER SEGMENT



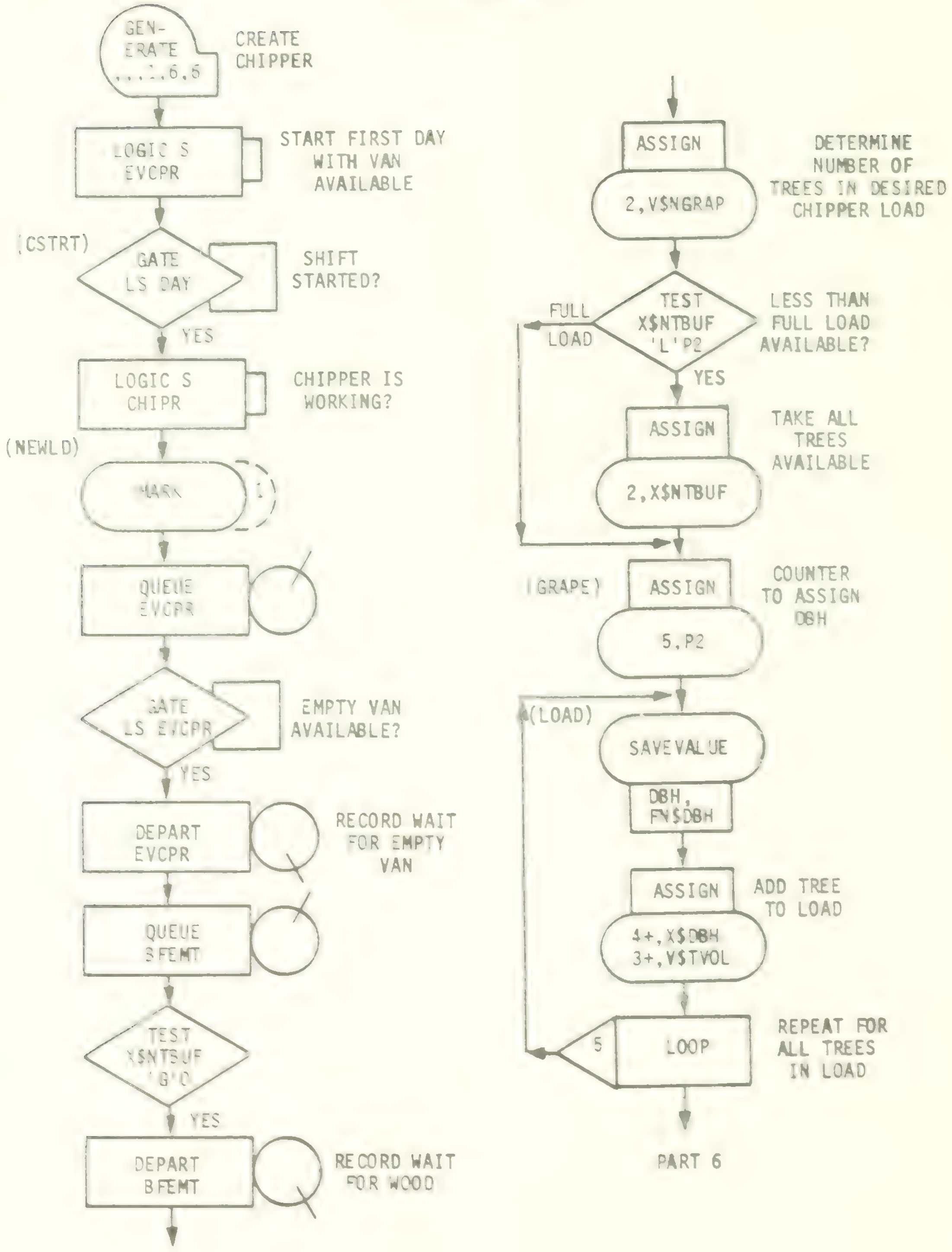
COMPOETE FLOW CHARTS - PART 4 OF 7

SKIDDER SEGMENT



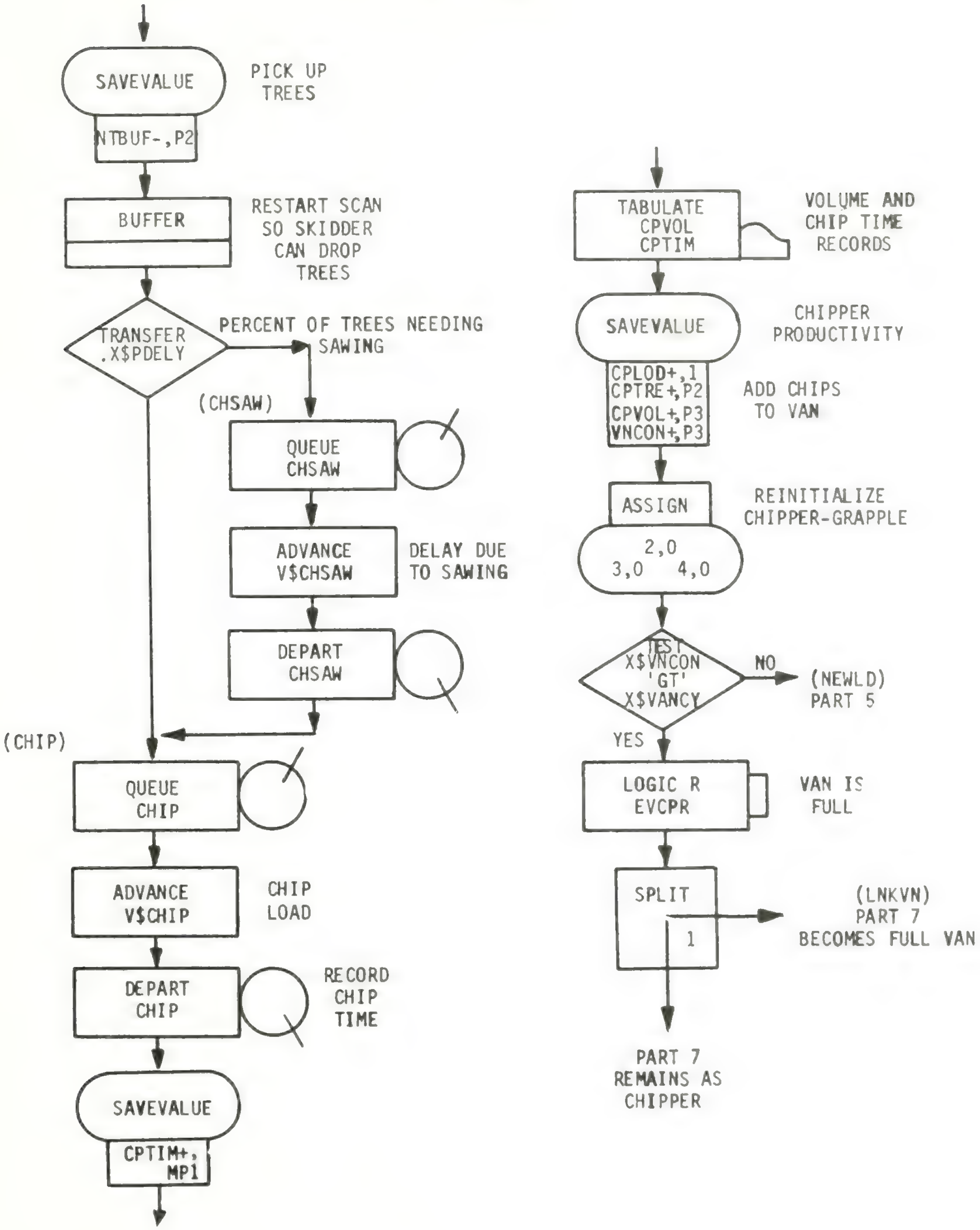
COMPLETE FLOW CHARTS - PART 5 OF 7

CHIPPER SEGMENT



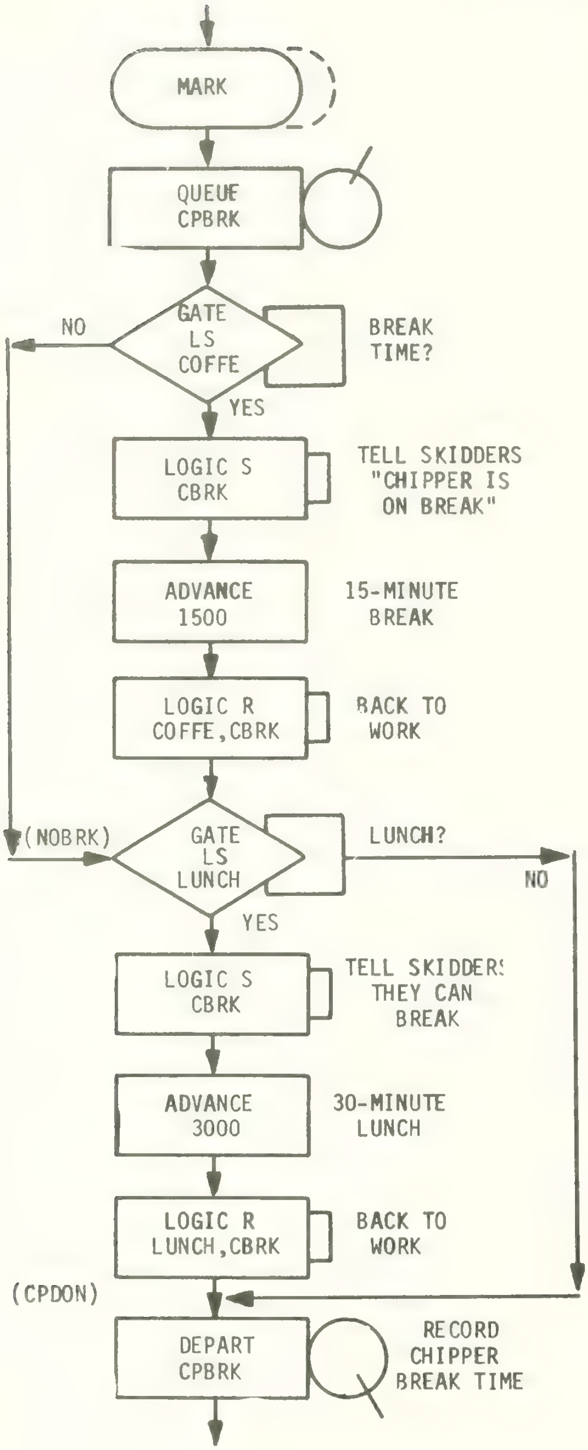
COMPLETE FLOW CHARTS - PART 6 OF 7

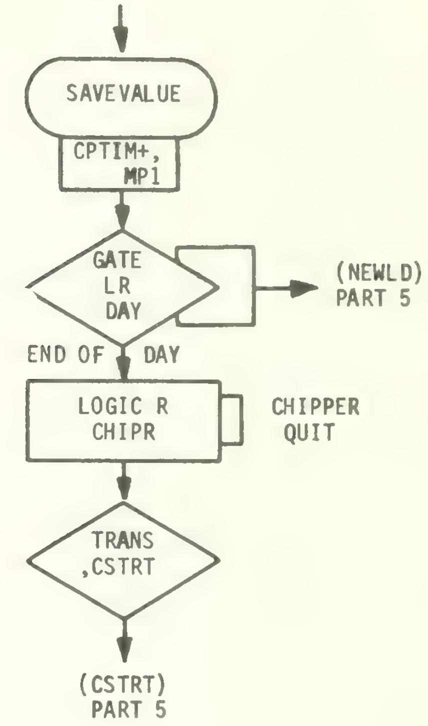
CHIPPER SEGMENT

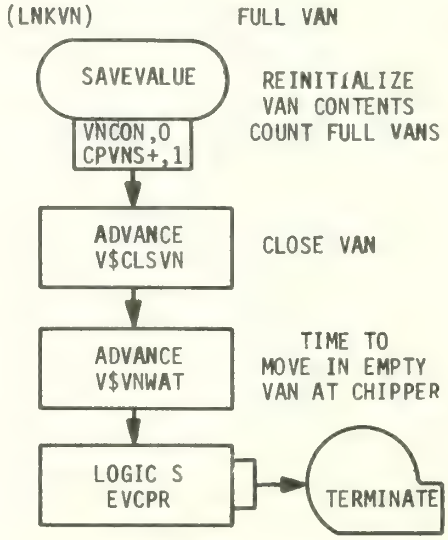


COMPLETE FLOW CHARTS - PART 7 OF 7

CHIPPER SEGMENT







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Winsauer, Sharon A.

A program and documentation for simulation of grapple skidders and a whole-tree chipper. Res. Pap. NC-221. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 42 p.

Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate a skidding-chipping operation.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.

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Paper **NC-222**

Volume Tables for Second-Growth Northern Hardwood Forests in Northeastern Wisconsin

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Gayne G. Erdmann, Thomas R. Crow, and Robert R. Oberg

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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1982

VOLUME TABLES FOR SECOND-GROWTH NORTHERN HARDWOOD FORESTS IN NORTHEASTERN WISCONSIN

Gayne G. Erdmann, *Silviculturist,*
Thomas R. Crow, *Principal Research Ecologist,*
and
Robert R. Oberg, *Forestry Research Technician,*
Marquette, Michigan

This paper presents formulas for determining the peeled cubic-foot volume of four important northern hardwood species: sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia americana* L.), yellow birch (*Betula alleghaniensis* Britton), and white ash (*Fraxinus americana* L.). Factors for converting cubic volume to board-foot and cordwood volumes are also provided. The equations are useful for quick estimates of volumes in even-aged, second-growth, northern hardwood stands in northeastern Wisconsin. Only a tree list by species and d.b.h. class is required when using our formulas, and no corrections are needed for differences in form quotient, bark volume, and species taper.

STUDY AREA

Measurements were taken from 125 trees in three 40-acre second-growth northern hardwood stands on the Argonne Experimental Forest in northeastern Wisconsin. The stands are primarily even-aged but have some scattered residuals left from the commercial clearcutting days. Two stands averaged 60 years in age. The third stand was about 70 years old and contained a higher proportion of small saw log trees.

The uncut portions of these three stands contained 483 trees 4.6 inches d.b.h. and larger per acre of which 64 percent were sugar maple, 13 percent basswood, 4 percent yellow birch, and 5 percent white ash. Other species included: hemlock (*Tsuga canadensis* (L.) Carr.), red maple (*Acer rubrum* L.), American elm (*Ulmus americana* L.), paper birch (*Betula papyrifera* Marsh.), black cherry (*Prunus serotina* Ehrh.), aspen (*Populus* spp.), and eastern hophornbean (*Ostrya virginiana* (Mill) K. Koch). Basal area stocking of all trees 4.6 inches d.b.h. and over averaged 129 square feet per acre. The stands also probably contained another 8 to 10 square feet per acre of basal area in saplings.

Site indices based on stem analysis were 65 feet at reference age 50 years for sugar maple and yellow birch and about 70 feet for basswood and white ash in the three stands. The stands are growing on a broad, level to gently rolling ridgetop, in coarse loamy Alfic Fragoithod soils primarily of the Iron River series. However, some small areas with thin sand and gravel layers in the substratum classify as stambaugh. Small boulders are common on the surface and throughout the profile. Growing-season precipitation averages about 20 inches, but droughty periods are common in July and August.

METHODS

Fifty sugar maples, 34 basswoods, 26 white ashes, and 15 yellow birches, ranging from 4.6 to 20.0 inches d.b.h., were randomly selected from the three stands for constructing cubic-foot volume, cordwood volume, and Scribner board-foot volume tables. Most data were obtained from felled and sectioned trees, but some measurements were taken on a few large-diameter trees by using Swedish climbing ladders and bark gauges at the required sectioning points. Measurements for cubic-foot volumes included: diameters inside bark (d.i.b.) and outside bark (d.o.b.), bark thicknesses from a 1-foot stump to a 4.0-inch top at 8.3-foot intervals, and total tree heights to the nearest foot. Bark thickness was determined to the nearest 0.1 inch by taking four measurements at right angles on cross-sectional discs from the end of each section. In addition, measurements on saw log trees (9.6 inches d.b.h. and larger) included those needed to compute Scribner board-foot volumes to a variable merchantable top diameter that was limited by branches, defect, or other deformity, but not less than an 8.0-inch d.i.b. top. Cull volume was not estimated. Total cubic-foot volumes inside bark were computed for each tree over 4.6 inches d.b.h. using Smalian's formula for the stump, the stem in 8.3-foot (100-inch) lengths to a variable top d.i.b. of not less than 4.0 inches, the tip, and the branches to a 4.0-inch d.i.b. top.

Using Spurr's (1954) volume-line method, we constructed separate cubic-foot volume tables for sugar maple, basswood, yellow birch, and white ash (table 1). The sugar maple volume-line equations in table 2 were also used for calculating cubic-foot volumes of other less commonly associated species such as red maple and American elm. Merchantable cordwood and board-foot volumes can be derived from the total cubic-volume estimates by using appropriate converting factors for mean stand diameters (tables 3, 4, and 5). A cord was assumed to contain 79 cubic feet of solid wood in our cordwood computations.

EXAMPLE

For a simple example, we will use a 1-acre pure sugar maple stand containing only pulpwood and small saw log trees. The first step is to construct a stand table listing the number (N) of trees of each species by breast height diameter (D) classes. We usually separate the diameter classes into economic groupings for pulpwood-size trees (5- to 9-inch), small saw log trees (10- to 15-inch), and large saw log trees (over 16 inches).

The next step is to select the appropriate (sugar maple) volume-line equation for computing the total cubic-foot volume in pulpwood and small saw log trees (table 2).

$$V = -1.4702\ (N) + 0.1848\ (D^2N)$$

Then substitute the proper values for (N) and (D^2N) from the stand table (subtotal) summary into the formula for:

Volume in pulpwood trees

$V = -1.4702\ (144) + 0.1848\ (7{,}121) = 1{,}104$ cubic feet

Volume in saw log trees

$V = -1.4702\ (94) + 0.1848\ (13{,}764) = 2{,}405$ cubic feet

Table 1.—*Gross cubic-foot (peeled) volume in the entire stem of 60- to 70-year-old second-growth northern hardwoods on site index 65 land in northeastern Wisconsin*[1]

D.b.h. (inches)	Sugar maple	Basswood	White ash	Yellow birch
	Cubic feet			
5	3.2	2.5	2.6	4.4
6	5.2	4.6	4.6	6.3
7	7.6	7.1	7.0	8.5
8	10.4	10.0	9.8	11.1
9	13.5	13.3	12.9	14.1
10	17.0	17.0	16.3	17.4
11	20.9	21.1	20.2	21.1
12	25.1	25.6	24.4	25.1
13	29.8	30.4	29.0	29.4
14	34.8	35.7	33.9	34.1
15	40.1	41.3	39.2	39.2
16	45.8	47.3	44.9	44.6
17	51.9	53.7	50.9	50.3
18	58.4	60.5	57.3	56.4
19	65.2	67.7	64.1	62.9
20	72.4	75.3	71.2	69.7
21	80.0	83.2	78.7	76.8
22	88.0	91.6	86.6	84.3
23	96.3	100.3	94.8	92.1
24	105.0	109.5	103.4	100.3
25	114.0	119.0	112.4	108.9

Species: Sugar maple, Basswood, White ash, Yellow birch.

[1] The entire stem plus all merchantable branchwood (to a variable top d.i.b. of not less than 4.0 inches and a minimum length of 100 inches) is included.

Thus, we calculate 1,104 cubic feet in pulpwood trees and 2,405 cubic feet in saw log trees, giving a gross peeled total cubic-foot volume of 3,509 cubic feet in this 1-acre stand. If total cubic-foot or cordwood volume estimates are needed, we can use the total (N) and (D^2N) values from the stand table summary to obtain the same results:

Volume in entire stand

$V = -1.4702\ (238) + 0.1848\ (20{,}885) = 3{,}509$ cubic feet.

Because $BA = D^2N \times 0.005454$, volume-line equations can also be expressed in terms of N and BA (table 2). For example, the equation for sugar maple, $V = 1.4702\ (N) + 0.1848\ (D^2N)$ would then be $V = 1.4702\ (N) + 33.88\ (BA)$. This form is ideal for a prism cruise in which BA and N are tallied by species. N and BA could be for the entire diameter range, could be divided into economic size classes (pulpwood, saw log), or could be the amount of wood to be removed in a sale.

Sugar Maple Stand Tables

Group	Diameter	D^2	Trees	D^2N	Total basal area ($BA = D^2N \times 0.005454$)
	Inches		*Number/acre*		
Pulpwood trees	5	25	38	950	5.2
	6	36	29	1,044	5.7
	7	49	23	1,127	6.1
	8	64	22	1,408	7.7
	9	81	32	2,592	14.1
		Subtotal	144	7,121	38.8
Small saw log trees	10	100	26	2,600	14.2
	11	121	18	2,178	11.9
	12	144	15	2,160	11.8
	13	169	12	2,028	11.1
	14	196	13	2,548	13.9
	15	225	10	2,250	12.3
		Subtotal	94	13,764	75.2
Total			238	20,885	114.0

Table 2.—*Total cubic-foot (peeled) volume formulas for the entire stems of 60-year-old second-growth northern hardwoods on site index 65 land for sugar maple at reference age 50*[1]

Species	Volume-line equations for a stand of trees[2]		Basis
			No. of trees
Sugar maple	$V = -1.4702\,(N) + .1848\,(D^2N)$	$V = -1.4702\,(N) + 33.88\,(BA)$	50
Basswood	$V = -2.3942\,(N) + .1942\,(D^2N)$	$V = -2.3942\,(N) + 35.61\,(BA)$	34
White ash	$V = -1.9425\,(N) + .1829\,(D^2N)$	$V = -1.9425\,(N) + 33.53\,(BA)$	26
Yellow birch	$V = -0.0045\,(N) + .1742\,(D^2N)$	$V = -0.0045\,(N) + 31.94\,(BA)$	15

[1] SI_{50} also 65 for yellow birch and about 70 for basswood and white ash.

[2] After Spurr's (1954) volume-line method.

Board-foot and cordwood volumes can be estimated by applying the proper conversion factors (from tables 3, 4, and 5) to the cubic-foot volumes for a specific mean stand diameter. Mean stand diameter is found by taking the square root of the sum of the products of D^2N divided by N from the stand table subtotals. Thus, the mean diameter for the pulpwood portion of the sugar maple stand is $\sqrt{\frac{7,121}{144}} = 7.0$ inches, while the saw log portion is $\sqrt{\frac{13,764}{94}} = 12.1$ inches. The mean diameter for the entire stand is $\sqrt{\frac{20,885}{238}} =$ 9.4 inches.

From table 3 we get a converting factor of 0.0099 for a pulpwood portion of the stand with a mean diameter of 7 inches. The cordwood volume for this portion of the stand is estimated by multiplying the total cubic-foot volume of 1,104 by 0.0099, resulting in 10.9 cords. Following the same procedures for the saw log portion of the stand with 12.1-inch average diameter, we get a 0.0107 converting factor and (0.0107 x 2,405 cubic feet) a 25.7 cord estimate, making a total stand estimate of 36.6 cords. Using 9.4 as the mean diameter of the entire stand and a 0.0105 converting factor with 3,509 cubic feet, we get an estimate of 36.8 cords—essentially the same amount we found by breaking the stand down into pulpwood and saw log components.

Table 3.—*Factors to convert total cubic-foot (peeled) volumes to peeled* cordwood volumes[1]

Mean stand d.b.h. (inches)	Species			
	Sugar maple	Basswood	White ash	Yellow birch
	Converting factors			
5	0.0077	0.0077	0.0077	0.0056
5.5	.0085	.0084	.0085	.0074
6	.0094	.0088	.0091	.0084
6.5	.0097	.0092	.0096	.0091
7	.0099	.0095	.0100	.0096
8	.0103	.0101	.0105	.0103
9	.0105	.0105	.0106	.0105
10	.0106	.0110	.0107	.0105
11	.0107	.0112	.0109	.0106
12	.0107	.0115	.0110	.0106
13	.0108	.0115	.0111	.0107
14	.0109	.0116	.0112	.0107
15	.0110	.0117	.0113	.0108
16	.0111	.0118	.0114	.0109
17	.0112	.0119	.0115	.0109
18	.0113	.0119	.0016	.0110
19	.0114	.0120	.0116	.0110
20	.0115	.0120	.0116	.0110

[1] Minimun top d.i.b. of 4.0 inches and minimum length of 8.3 feet (100 inches).

The converting factors in table 4 are handled like those in table 3. Thus, our 12.1-inch saw log stand would contain (0.0018 x 2,405 cubic feet) about 4.3 cords in peeled cordwood above an 8.0-inch d.i.b. top and in branchwood up to a minimum diameter of 4.0 inches d.i.b. and a minimum length of 8.3 feet.

Table 4.—*Factors to convert total cubic-foot (peeled) volumes above an 8-inch d.i.b. top on saw log trees to peeled cordwood volumes*[1]

Mean stand d.b.h. (inches)	Species			
	Sugar maple	Basswood	White ash	Yellow birch
	Converting factors			
10	0.0042	0.0050	0.0054	0.0040
10.5	.0036	.0041	.0043	.0032
11	.0030	.0033	.0035	.0025
11.5	.0025	.0027	.0031	.0021
12	.0018	.0023	.0028	.0019
12.5	.0013	.0021	.0027	.0018
13	.0010	.0019	.0027	.0016
14	.0008	.0017	.0025	.0013
15	.0007	.0014	.0023	.0011
16	.0006	.0012	.0020	.0010
17	.0007	.0011	.0018	.0008
18	.0010	.0010	.0017	.0008
19	.0018	.0010	.0016	.0008
20	.0028	.0010	.0015	.0008

[1] Minimun top d.i.b. of 4.0 inches and minimum length of 8.3 feet. Stem branchwood included.

Table 5.—*Factors to convert total cubic-foot (peeled) volumes to Scribner board-foot volumes*[1]

Mean stand d.b.h. (inches)	Species			
	Sugar maple	Basswood	White ash	Yellow birch
	Converting factors			
10	1.7	1.4	1.3	2.1
10.5	2.3	2.1	2.2	2.5
11	2.8	2.6	2.7	2.7
11.5	3.2	2.9	3.0	2.9
12	3.5	3.2	3.3	3.1
12.5	3.7	3.5	3.4	3.2
13	3.9	3.7	3.5	3.4
14	4.2	3.9	3.7	3.6
15	4.4	4.1	3.9	3.8
16	4.6	4.3	4.0	3.9
17	4.7	4.4	4.1	4.0
18	4.8	4.5	4.2	4.1
19	4.8	4.6	4.3	4.2
20	4.6	4.7	4.4	4.3
(No. of trees)	(50)	(34)	(26)	(15)

[1] Minimun top d.i.b. of not less than 8.0 inches but variable depending on branches, defect, or other deformity that limited merchantable height.

Finally, our 12.1-inch saw log portion of the stand contains 8,417 board feet (gross Scribner), which is obtained by multiplying the 3.5 (conversion factor from table 5) by 2,405 cubic feet.

APPLICABILITY

These tables give better estimates in our study area than the composite volume tables of Gevorkiantz and Olsen (1955). Their tables have wide applicability but are commonly misused because corrections for differences in form class, bark thickness, and taper are often not applied when needed. Our tables do not have to be adjusted for these factors. Our tables and formulas are useful for estimating standing volumes and volumes to be removed in 60- to 70-year-old second-growth stands that have heavy proportions of sugar maple on similar sites (65 at 50 years for sugar maple) in northeastern Wisconsin. However, Gevorkiantz and Olsen (1955) have a better data base for applying their tables to large areas of the Lake States. Hahn (1973) also has developed a separate set of local tree volume equations for different species groups in Wisconsin.

Our formulas are very useful for quick estimates of cordwood volumes to be removed in sugar maple firewood sales. All that is required from the field is a stand table summary listing by full-inch diameter classes the number (N) of trees to be removed. Merchantable or total heights do not need to be measured because they were taken into account in developing the equations.

LITERATURE CITED

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Spurr, S. H. Simplified computation of volume growth. J. For. 52: 914-922; 1954.

Erdmann, Gayne G.; Crow, Thomas R.; Oberg, Robert R.
Volume tables for second-growth northern hardwood forests in northeastern Wisconsin.Research Paper NC-222. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 5 p.

Cubic-foot volume equations are presented for sugar maple, basswood, yellow birch, and white ash. Conversion factors for board-foot and cordwood volumes are also provided. The equations are useful for even-aged, second-growth hardwoods in northeastern Wisconsin.

KEY WORDS: sugar maple, yellow birch, American basswood, white ash, cubic volume, board-foot, cordwood.

U.S. GOVERNMENT PRINTING OFFICE:1982-665-447/158

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-223**

Roller Chopping for Site Preparation in Wisconsin: A Case Study

Edwin S. Miyata, Helmuth M. Steinhilb, Robert L. Sajdak, and Michael Coffman

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ROLLER CHOPPING FOR SITE PREPARATION IN WISCONSIN: A CASE STUDY

Edwin S. Miyata, *Research Industrial Engineer,*
Helmuth M. Steinhilb, *Research Forester,*
North Central Forest Experiment Station,
Houghton, Michigan,
Robert L. Sajdak, *Assistant Professor,*
Forestry Department, Michigan Technological University,
Houghton, Michigan,
and **Michael Coffman,** *Silviculturist,*
Champion International Corporation,
Norway, Michigan

Throughout the United States, concern for wood fiber shortage has focused attention on converting poor quality hardwood stands to more productive conifers. From 1980 to the year 2000, pulpwood consumption is expected to double (U.S. Department of Agriculture Forest Service 1973).

In the Lake States, pulpwood is the dominant product (fig. 1) (Blyth *et al.* 1980). Escalating softwood stumpage prices and conifer shortages motivate land owners to convert low value, slower growing hardwoods to high value, fast growing softwoods.

To achieve optimum growth of conifers in plantations, good site preparation is essential. It has long been recognized that vegetative competition can significantly reduce the rate of survival and subsequent growth in plantations (Stone and Chase 1962). Investigators have noted that without good site preparation, plantations will normally fail if planted under the mixed aspen/hardwood overstory typically found on most conversion sites (Fox 1973, Rudolph 1950). But with good site preparation, early height growth can be increased 50 to 100 percent (Knighton 1972, Roe 1955), and volume growth can be improved by as much as 60 to 300 percent (Wittenkamp and Wilde 1964). To achieve good survival and growth of red pine on a mixed aspen/hardwood site, most competing vegetation should first be removed by harvesting all merchantable materials. Then, the site should be prepared by shearing, roller chopping, barrel scarifying, root raking, burning, and/or applying chemicals (Fox 1973, Benzie 1977, Perala 1977). Several treatments are often better than one, and chemical treatment is almost always necessary after aspen or hardwood site conversion.

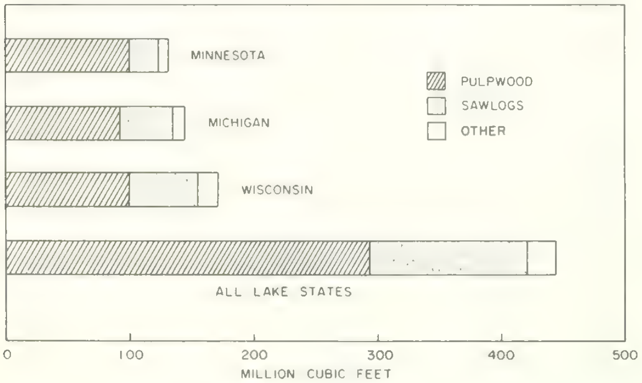

Figure 1.—*Lake States roundwood production by type of product, 1975 (Blyth* et al., *1980).*

Among the various site preparation techniques, interest in mechanical or chemical treatment of cutover areas to prepare for the planting of conifers has been increasing in the Lake States. However, production and cost data on site preparation are needed to analyze and establish economically feasible site preparation techniques. This paper presents the results of a cost and productivity study of roller chopping to prepare a cutover aspen site for conversion to red pine.

STAND DESCRIPTION

In August 1980 the Forestry Sciences Laboratory in Houghton, Michigan, in cooperation with the Champion International Corporation and Michigan Technological University, conducted a field study of the cost and effectiveness of roller chopping on 54.4 acres in Sections 9 and 10, T.37N, R.17E, Marinette County, Wisconsin. The area had been logged for aspen pulpwood about 6 months before and now consisted of a stand of small aspen and aspen sprouts averaging 3 inches d.b.h. with a basal area of 15 sq ft/acre (fig. 2). The topography was level except for a few localized knolls that had slopes up to 30 percent. The soil was sandy and dry. Future plans for the area call for additional treatments of roller chopping or herbicides during summer 1981 and planting of red pine in spring 1982.

EQUIPMENT USED

The equipment used on the project was an International TD-15C Pay Dozer pulling a Model LRC812 single drum roller chopper manufactured by the Lucas Machine and Welding Company, Inc. (fig. 3).[1]

The TD-15C Pay Dozer weighed 31,520 pounds equipped with the dozer and hydraulic control system. The machine had a 4-cycle diesel turbocharged engine, which developed 140 net flywheel horsepower at 2,500 rpm. The dozer blade, hydraulically controlled for lift, pitch, and angle, was 120 inches wide.

The roller chopper had a 5-foot o.d. drum, 8 feet wide, equipped with 12 (3/4" x 10" x 8') cutting blades equally spaced around the circumference of the drum. The drum was filled with 550 gallons of water to give the machine a total weight of 18,200 pounds.

OPERATION

The equipment operator followed a circular pattern of roller chopping by first running a strip around the perimeter of the area. Succeeding courses were chopped inside the perimeter strip in a circular or spiral pattern until the work was completed at the center of the tract.

The dozer was used to push over the standing trees in the direction of travel; the roller chopper then passed over the felled trees and logging debris on the ground, reducing the material to smaller pieces.

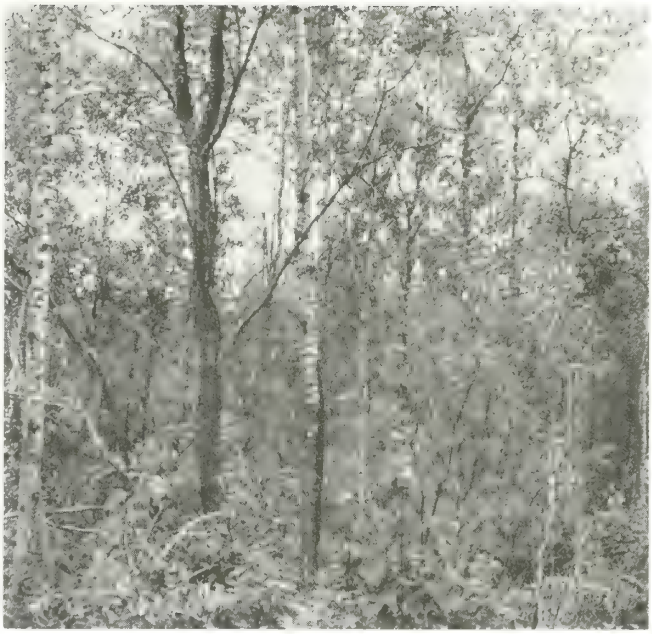

Figure 2.—Cutover aspen stand before roller chopping.

RESULT

In general, the machine chopped the woody material effectively. The smaller dried stumps remaining after the logging were often broomed and split by the chopper blades (fig. 4). Green stumps more than 6 inches in diameter were rarely affected (fig. 5). Bole material 3 inches in diameter or less oriented in the direction of the machine's travel was usually chopped into short pieces (fig. 6). Dry logging debris was better chopped than green wood (fig. 7).

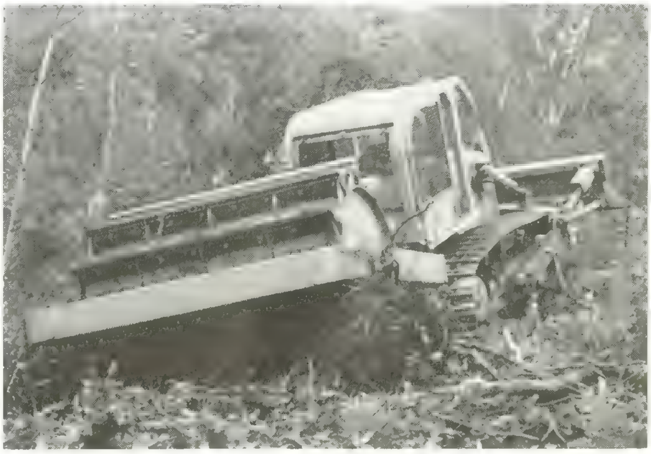

Figure 3.—*Equipment used for roller chopping.*

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[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

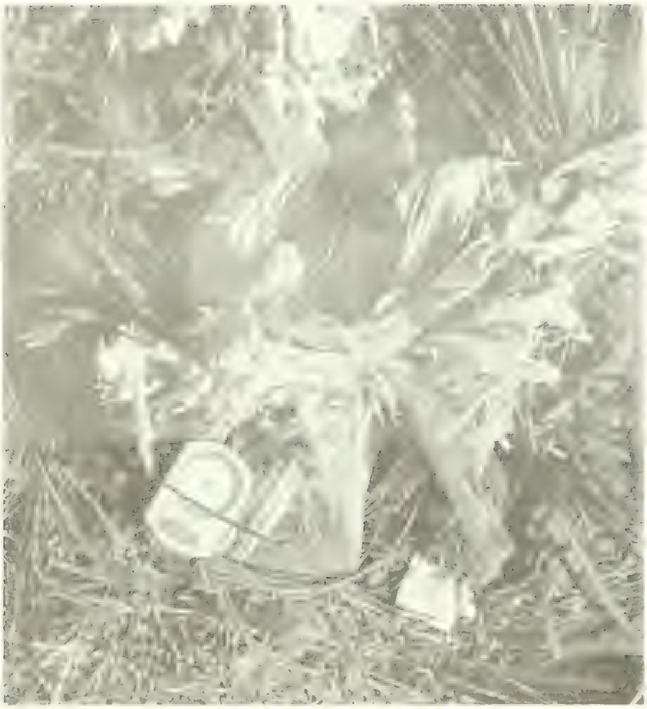

Figure 4.—*Splitting and brooming of dried stump caused by roller chopping.*

Sometimes the dozer blade "scalped" the surface of the ground, exposing the bare soil. The cutting blades of the roller chopper sank several inches into the ground, severing the roots and loosening the top 4 to 8 inches of litter and soil (fig. 8). Figure 9 is an overall view of the area after roller chopping.

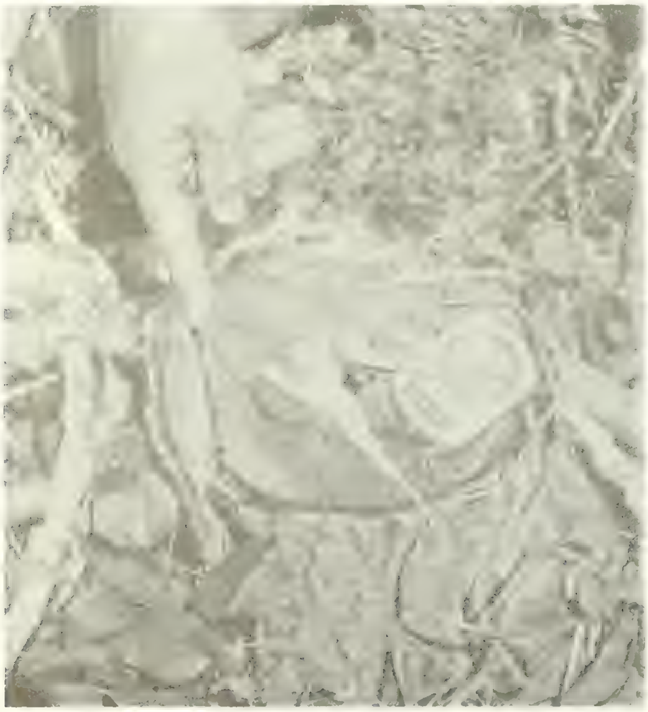

Figure 5.—*Solid stump more than 6 inches in diameter, little affected by roller chopping.*

Figure 6.—*Material less than 3 inches in diameter chopped into short pieces.*

The machine operated on slopes up to 25 percent but had difficulty on slopes steeper than that. On 30-percent slopes, the machine could operate well only when traveling downhill.

Productivity data are summarized as follows:

Average width of swath	8 feet
Total area chopped	54.4 acres
Total machine time	35.0 hours
Productivity	1.55 acres/hour
Average travel time when chopping	171 feet/minute
Operator time (includes travel to and from job, machine maintenance, etc.)	51 hours
Supervision	19 hours

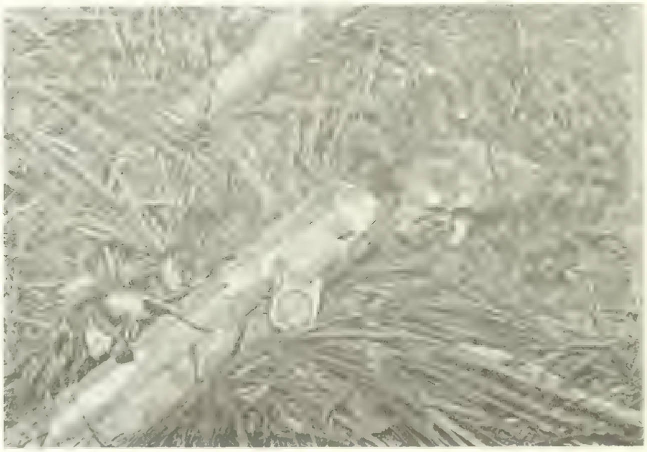

Figure 7.—*Effect of roller chopping on 4-inch diameter dry logging debris.*

Figure 8.—*Cutting blades of roller chopper sink into ground, loosening the top 4 to 8 inches of litter and soil.*

Figure 9.—*Overall view of the area after roller chopping.*

Based on our assumptions (tables 1 and 2) and the 1980 purchase cost for the equipment, the machine costs for the TD-15C and the Lucas roller chopper were calculated as $41.63 and $2.92, respectively, per productive hour or a combined cost of $44.55 per productive hour as shown in the following tabulation:

Itemized equipment cost (1980 dollars):

Machine	Initial cost	Cost/hour (without labor)		
		Fixed	Operating	Total
1 International Bulldozer TD-15C	$104,097	$24.03	$17.60	$41.63
1 Lucas Roller Chopper 812	16,848	2.81	.11	2.92

Cost per acre is estimated as:

	Total cost	Cost/acre	Percent
Total machine cost ($44.55/hr x 35 hr)	$1,559.25	$28.66	67
Operator cost[2] ($10/hr x 51 hr)	510.00	9.38	22
Supervision[2] ($14/hr x 19 hr)	266.00	4.89	11
TOTALS	$2,335.25	$42.93	100

DISCUSSION AND RECOMMENDATIONS

The productivity of 1.55 acres/hour and cost of $42.93/acre obtained on this project are comparable to those realized in site preparation work in the southern United States. Productivity of roller chopping on Crown Zellerbach Corporation's southern clearcut site preparation projects, using crawler tractors for motive power, range from 1.3 to 1.7 acres hour (Forest Industries 1976). Roller-chopping costs for site preparation in the northern coastal plain region average $28.11 machine cost, $9.52 labor cost, and $2.21 supervision cost/acre (Moak *et al.* 1980).

The machine operator on our study had no previous experience in roller chopping and needed more supervision than normal. As the operator gains more experience, supervision cost should be reduced and productivity increased to 1.6-1.8 acres/hour (based on chopping speed of 171 feet/minute) by minimizing turnaround and unnecessary chopping travel.

Crown Zellerbach Corporation uses a large, wheeled skidder and roller chopper on the flat areas in the South to increase the productivity of site preparation from an average of 1.5 acres/hour when using crawler tractors to 3.2 acres/hour with a skidder (Forest Industries 1976). Burns and Hebb (1972) also reported that in 15 years, planted slash pine on sites prepared by burning and double chopping grew 4 feet higher and 0.4 inch larger in d.b.h. than pine on single-chopped sites. Further study is recommended to determine the effectiveness and cost of double chopping and to see if using a large, wheeled skidder and roller chopper would increase the productivity of site preparation on flat land in the Lake States.

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[2] *Labor cost assumed.*

Table 1.--Calculation of the hourly machine rate for a TD-15C International bulldozer

MACHINE RATE

Description

Manufacturer International Bulldozer Model TD-15C H.P. 140

Purchase Cost: $104,097.00

Less: Tire Cost - -

Total Initial Investment (P) $ 104,097.00

Salvage Value (S) (20 % of P) $ 20,819.00

Estimated Life (n) 5 years

Working Days/Year 250 days

Scheduled Hours/Year (SH) 2,000 SH

Utilization (U) 70 %

Productive Hours/Year (PH) 1,400 PH

Average Value of Investment (AVI) = $\frac{(P - S)(n + 1)}{2n} + S$ $ 70,786.00 /yr

II. Fixed Cost

Depreciation (D) = $\frac{P - S}{n}$ $ 16,656.00 /yr

Interest 18 %
Insurance 3 %
Taxes 3 %

Total 24 % X (AVI = $ 70,786.00 /yr) $ 16,989.00 /yr
Total fixed cost per year $ 33,645.00 /yr
Fixed cost per SH $ 16.82 /SH
Fixed cost per PH (A) * $ 24.03 /PH

III. Operating Cost

Maintenance and Repair $\frac{(100\ \%\ \text{of}\ (P - S))}{n \times PH}$ $ 11.90 /PH

Fuel Cost $ 5.20 /PH
Oil and Lubricants $ .50 /PH

Tires = $\frac{1.15 \times \text{tire price}}{\text{Total tire life in hours (miles)}}$ $ - /PH

TOTAL OPERATING COST PER PH (B) * $ 17.60 /PH

* Machine Rate per PH (A + B) $ 41.63 /PH

Table 2.--Calculation of the hourly machine rate for a LRC 812 Lucas Machine and Welding Roller Chopper

MACHINE RATE

Description

Manufacturer Lucas Machine & Welding Model Roller Chopper LRC 812 H.P. -

Purchase Cost: $16,848.00

Less: Tire Cost - -

Total Initial Investment (P) $ 16,848.00

Salvage Value (S) (20 % of P) $ 3,369.60

Estimated Life (n) 10 years

Working Days/Year 250 days

Scheduled Hours/Year (SH) 2,000 SH

Utilization (U) 70 %

Productive Hours/Year (PH) 1,400 PH

Average Value of Investment (AVI) = $\frac{(P - S)\ (n + 1)}{2n} + S$ $ 10,782.72 /yr

II. Fixed Cost

Depreciation (D) = $\frac{P - S}{n}$ $ 1,347.84 /yr

Interest 18 %
Insurance 3 %
Taxes 3 %

Total 24 % X (AVI = $ 10,782.72 /yr) $ 2,587.85 /yr
Total fixed cost per year $ 3,935.69 /yr
Fixed cost per SH $ 1.97 /SH
Fixed cost per PH (A) * $ 2.81 /PH

III. Operating Cost

Maintenance and Repair (10 % of $\frac{(P - S))}{n \times PH}$ $ 0.10 /PH

Fuel Cost $ - /PH
Oil and Lubricants $ 0.01 /PH

Tires = $\frac{1.15 \times \text{tire price}}{\text{Total tire life in hours (miles)}}$ $ - /PH

TOTAL OPERATING COST PER PH (B) * $ 0.11 /PH

* Machine Rate per PH (A + B) $ 2.92 /PH

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Roller chopping for site preparation in Wisconsin: a case study. Res. Pap. NC-223. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station; 1982. 8p.

Analyzes the cost and productivity of roller chopping in preparing a cutover aspen stand for conifer conversion (1.55 acres hour at $43 acre).

KEY WORDS: Mechanical site preparation, stand conversion, aspen, red pine.

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Estimating Stump Volume

Gerhard K. Raile

PUBLIC DOCUMENTS

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ESTIMATING STUMP VOLUME

Gerhard K. Raile,
Associate Mensurationist

A technique for estimating volume in stumps[1] of various heights given d.b.h. (tree diameter at breast height), has several uses: (1) stump volumes can be used as one component in calculating total aboveground biomass; (2) tree utilization factors can be computed; (3) an economic analysis can be made of harvesting to various stump heights; and (4) forest inventory statistics, which assume a known stump height, can be adjusted for any other stump height.[2]

Interest in stump weight and volume has developed recently as foresters have sought ways to produce and harvest more usable tree biomass per acre of forest land. Young *et al.* (1964) were among the first to develop regression equations to estimate the weight of the complete tree and its components. Young and other researchers have produced regression equations that use d.b.h. to predict the combined weight of stump and/or roots (King and Schnell 1972, Schnell and Toennisson 1978, Dyer 1967, Keays 1971).

Few studies deal with stump volume (as opposed to weight) as a separate component of total volume. Drolet (1973) presents data on the volume of merchantable wood left in stumps after normal harvesting. Decei *et al.* (1975) developed a linear regression model for spruce to predict stump volume from the bole volume. They found the average ratio of stump volume to bole volume to be 0.101 under normal harvesting conditions.

OBJECTIVE AND MODEL CRITERIA

The objective of this study was to develop a technique for estimating the volume both inside and outside bark of any stump section between ground level and 4.5 feet given d.b.h. and stump heights (h). Equations were developed that predict stump diameter inside (d.i.b.) and outside (d.o.b.) bark. These equations are used to compute stump volume both with and without bark.

These models had to: (1) fit the data well, (2) give reasonable diameter estimates between ground level and 4.5 feet, (3) give consistent results for d.i.b. and d.o.b., (4) use independent variables normally available in existing inventory data, and (5) be functions that can be modified and/or integrated to compute stump volume.

The following mathematical technique is used in computing volume:

Given that d = f (d.b.h., h),
where h = height above ground level ($0 \leq h \leq 4.5$),
d.b.h. = a constant, and
d = either d.o.b. or d.i.b. at height h;

then the volume in the stump section (V) between heights a and b is

$$V = \frac{\pi}{4}\int_a^b [\, f(\text{d.b.h.}, h)\,]^2\, dh,\ 0 \leq a < b \leq 4.5 \qquad (1)$$

DATA

Data were collected from 2,975 trees as part of forest product utilization studies conducted in conjunction with forest inventories in Michigan, Minnesota, and Wisconsin (tables 1 and 2). Measurements taken from random samples of felled trees at logging operations in these States were d.b.h., double bark thickness at d.b.h., stump height, and d.i.b. at stump height. In addition, the d.o.b. was measured at half-foot intervals from 0.5 to 2.5 feet above ground level. On slopes, measurements were taken from ground line on the uphill side. All measurements were taken to the last 0.1 inch. Where an abnormality such as a bulge or a fork occurred, the observation was not taken.

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[1] *Stump is defined as the tree bole from ground level to any height less than or equal to 4.5 feet.*

[2] *For applications where d.b.h. is unknown, equations that predict d.b.h. from stump measurements may be used (Raile 1978).*

MODEL FOR PREDICTING D.O.B.

Pearson correlation coefficients and stepwise regression techniques were used to develop the following model:

$$\text{d.o.b.} = \text{d.b.h.} + B(\text{d.b.h.})\,\frac{4.5\text{-}h}{h+1}, \qquad (2)$$

where B is the species group regression parameter.

This model was fit for 22 species groups. The species included in each species group are listed below. Table 1 presents the regression coefficient, coefficient of determination (R^2) and standard error (SE) for each species group. Figure 1 shows how the model fits the data. In this graph the predicted d.o.b. is plotted against a 10-percent random sample of observed d.o.b. for red pine, *Pinus resinosa* Lamb.

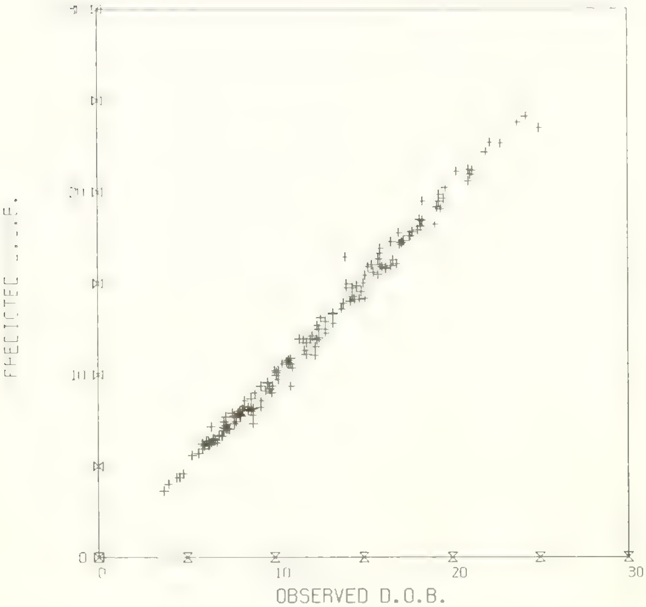

Figure 1.—*Predicted vs. observed d.o.b. for red pine.*

SPECIES GROUP LIST

Common name	**Scientific name**
SOFTWOODS	
Eastern white pine	*Pinus strobus* L.
Red pine	*Pinus resinosa* Ait.
Jack pine	*Pinus banksiana* Lamb.
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Balsam fir	*Abies balsamea* var. *balsamea* (L.) Mill.
Hemlock	*Tsuga canadensis* (L.) Carr.
Northern white-cedar	*Thuja occidentalis* L.
HARDWOODS	
White oaks	*Quercus alba* L. *Quercus bicolor* Willd. *Quercus macrocarpa* Michx.
Red oaks	*Quercus rubra* L. *Quercus ellipsoidalis* E.J. Hill
Beech	*Fagus grandifolia* Ehrh.
Yellow birch	*Betula alleghaniensis* Britton
Hard maples	*Acer nigrum* Michx.f. *Acer saccharum* Marsh.
Soft maples	*Acer rubrum* var. *rubrum* L. *Acer saccharinum* L.
White & green ash	*Fraxinus americana* L. *Fraxinus pennsylvanica* Marsh.
Black ash	*Fraxinus nigra* Marsh.
Paper birch	*Betula papyrifera* var. *papyrifera* Marsh.
Bigtooth aspen	*Populus grandidentata* Michx.
Quaking aspen	*Populus tremuloides* Michx.
Basswood	*Tilia americana* L.
Cottonwood	*Populus deltoides* Bartr. ex Marsh.
Elms	*Ulmus americana* L. *Ulmus rubra* Muhl. *Ulmus thomassii* Sarg.

MODEL FOR PREDICTING D.I.B.

To estimate d.i.b., equation (2) was modified as follows:

$$\text{d.i.b.} = A(\text{d.b.h.}) + B(\text{d.b.h.})\,\frac{4.5\text{-}h}{h+1} \qquad (3)$$

where A and B are the species group regression parameters (table 2).

D.i.b. was only measured at stump height and 4.5 feet. To estimate d.i.b. at half-foot intervals from 0.5 to 2.5 feet, it was assumed that the ratio of d.i.b. to d.o.b. at stump height is constant in this range. This assumption increased the number of observations available for fitting the equations.

Table 1.—*Stump d.o.b. regression coefficients for tree species of the Lake States*

Species group	Trees	D.b.h. range	Observations	D.o.b. range	Species parameter B	R^2	SE
	No.	*Inches*	*No.*	*Inches*			*Inches*
E. white pine	53	6.2-33.0	359	6.2-47.2	0.11694	0.89	1.2
Red pine	228	3.4-23.0	1,544	3.4-27.9	.08091	.91	.5
Jack pine	579	3.4-19.4	3,843	3.4-24.0	.08076	.87	.5
White spruce	34	5.1-18.0	223	5.1-30.9	.16903	.86	1.2
Black spruce	103	3.6-17.9	712	3.6-27.4	.12147	.73	.9
Balsam fir	119	4.3-15.4	706	4.3-26.0	.15359	.89	.8
Hemlock	57	5.8-29.0	371	5.8-42.5	.12667	.85	1.3
N. white-cedar	14	4.8-13.3	96	4.8-22.3	.18850	.89	.9
White oaks	61	4.2-26.2	377	4.2-43.7	.14872	.84	1.3
Red oaks	214	2.5-28.7	1,309	2.5-37.9	.12798	.83	1.2
Beech	29	4.5-24.3	167	4.5-38.8	.15113	.79	1.8
Yellow birch	41	7.5-28.1	271	7.5-39.4	.15350	.78	2.0
Hard maples	132	2.3-31.3	743	2.3-37.8	.12111	.76	1.6
Soft maples	74	2.5-20.8	340	2.5-28.0	.11585	.77	1.2
White & green ash	37	7.3-24.7	256	7.3-44.8	.12766	.75	1.5
Black ash	15	7.9-17.5	87	7.9-25.5	.17376	.93	.9
Paper birch	178	3.2-22.4	974	3.2-34.7	.11655	.77	1.0
Bigtooth aspen	204	4.0-15.6	895	4.0-21.6	.06834	.82	.5
Quaking aspen	678	2.9-20.5	3,920	2.9-29.0	.09658	.83	.8
Basswood	38	6.4-26.7	178	6.4-42.0	.14413	.86	1.4
Cottonwood	7	12.8-27.8	42	12.8-48.2	.17123	.85	2.1
Elms	80	7.0-30.5	464	7.0-49.2	.16638	.84	1.6

Table 2.—*Stump d.i.b. regression coefficients for tree species of the Lake States*[1]

Species group	Observations	D.I.B. range	Species parameter A	Species parameter B	R^2	SE
	No.	*Inches*				*Inches*
E. white pine	360	6.0-43.9	0.91385	0.11182	0.86	1.2
Red pine	1,551	3.0-25.8	.90698	.08469	.87	.7
Jack pine	3,873	3.1-23.4	.90973	.07926	.84	.6
White spruce	225	4.9-29.7	.95487	.15664	.83	1.2
Black spruce	713	3.4-26.4	.94122	.11781	.69	1.0
Balsam fir	725	4.0-25.4	.93793	.14553	.87	.9
Hemlock	375	5.0-41.0	.91400	.11975	.79	1.4
N. white-cedar	96	4.6-22.2	.94698	.18702	.86	1.0
White oaks	384	3.7-42.3	.91130	.14907	.83	1.4
Red oaks	1,339	2.3-40.3	.92267	.12506	.81	1.3
Beech	172	4.3-36.5	.96731	.14082	.79	1.6
Yellow birch	273	7.1-37.8	.94423	.14335	.80	1.7
Hard maples	771	2.1-36.7	.93818	.11424	.75	1.5
Soft maples	369	2.4-26.3	.94181	.10740	.73	1.2
White & green ash	256	6.8-41.8	.91979	.12152	.72	1.6
Black ash	90	7.6-24.1	.93502	.17071	.94	.8
Paper birch	1,016	3.0-32.1	.93763	.10640	.75	.9
Bigtooth aspen	981	3.7-19.7	.91625	.06478	.71	.7
Quaking aspen	4,046	2.6-26.5	.91882	.08593	.78	.8
Basswood	192	6.1-37.3	.92442	.14240	.87	1.3
Cottonwood	43	11.8-47.1	.92736	.17626	.85	2.2
Elms	477	6.4-43.8	.93257	.15803	.82	1.6

[1] Number of trees and d.b.h. ranges for these regressions are the same as those given in Table 1.

COMPUTING STUMP VOLUME

The volume inside bark (V_i) for a section of the stump between a and b can now be found by substituting equation (3) into equation (1) and evaluating the definite integral. Because d.b.h. is in inches and his in feet, the equation to compute the volume in cubic feet becomes:

$$V_i = \frac{\pi}{4(144)} \int_a^b \left[A(\text{d.b.h.}) + B(\text{d.b.h.}) \frac{4.5-h}{h+1} \right]^2 dh \quad (4)$$

Integration of equation (4) gives:

$$V_i = \frac{\pi(\text{d.b.h.})^2}{4(144)} \left[(A-B)^2 h + 11B(A-B)\ln(h+1) - \frac{30.25}{h+1} B^2 \right]_a^b \quad (5)$$

The solution for volume outside bark is a special case of equation (5) where parameter A is equal to 1. Therefore equation (5) can be used to estimate stump section volumes both inside and outside the bark.

With this method, volumes both inside and outside bark can be computed for any stump section between ground level and 4.5 feet. The equation can be solved easily using a hand-held, programmable calculator or automated data processing systems. For example, the equation for cubic foot volume outside the bark of a 1-foot red-pine stump becomes:

$$V = 0.008240(\text{d.b.h.})^2$$

where d.b.h. is in inches.

The volumes obtained with this method have several characteristics worth noting. First, with these coefficients, the predicted d.o.b. is always greater than d.i.b. for stump heights between 0.0 and 4.5 feet. Therefore, the volume outside the bark is always greater than the volume inside the bark for any stump section. In addition, the volume obtained from equation (5) is always less than or equal to the volume computed assuming a neiloid frustum.

If direct observations of stump volume and d.b.h. were available, more reliable volume estimates might be obtained by fitting a regression to directly predict volumes. Our results suggest investigating a model as such:

$$V = \text{d.b.h.}^2 \left[A + Bh + C\,[\ln(h+1)] + D\,\frac{1}{h+1} \right]$$

where A through D are the regression coefficients.

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Equations are presented that predict diameter inside and outside bark for tree boles below 4.5 feet given d.b.h. These equations are modified and integrated to estimate stump volume. Parameters are presented for 22 Lake States species groups.

KEY WORDS: Taper model, Minnesota, Wisconsin, Michigan, biomass.

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The Susceptibility of Jack Pine from Lake States Seed Sources to Insects and Diseases

A.C. Hodson, D.W. French, R.A. Jensen, and R.J. Bartelt

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THE SUSCEPTIBILITY OF JACK PINE FROM LAKE STATES SEED SOURCES TO INSECT AND DISEASE PESTS[1]

A. C. Hodson, *Professor Emeritus,*
Entomology, Fisheries and Wildlife,
D. W. French, *Department Head and Professor,*
Plant Pathology,
R. A. Jensen, *Associate Scientist,*
Cloquet Forestry Center,
and **R. J. Bartelt,** *Research Associate,*
Entomology, Fisheries and Wildlife,
University of Minnesota, St. Paul, Minnesota

Jack pine (*Pinus banksiana* Lamb.) grown from seed collected from different locations varies in its susceptibility to attack by certain insects and diseases. The North Central Forest Experiment Station and the University of Minnesota worked together to determine the range in variability of jack pine susceptibility in the Lake States Region. Seed was collected from locations throughout Michigan, Wisconsin, and Minnesota and planted in several plantations within each State. Insect and disease incidence has been previously reported for plantations of the same seed sources located in National Forests of the three States (Arend *et al.* 1961, Batzer 1961, King and Nienstaedt 1965, King 1971, Jeffers and Jensen 1980). In this publication we report on the results of the disease and insect susceptibility found in three of the Minnesota plantations.

METHODS

In the fall of 1953 and the spring of 1954, jack pine seedlings grown from seed collected in Minnesota, Wisconsin, and Michigan were established in three plantations in Minnesota—at the Cloquet Forestry Center at Cloquet, at the General Andrews State Forest at Willow River, and at the Pillsbury State Forest north of Pillager. The origins of the seed sources and the planting design have been reported elsewhere (Jensen *et al.* 1960, King 1971). Four replicates of each of 29 sources plus jack pine grown from seed collected from one local source were planted in 4 randomized blocks of 30 sources at each location.

The 16 center trees in each of the four, 64-tree replicates for each seed source were identified by source number and examined in the early fall each year from 1955 through 1961. Type and height above ground of injury by insects or fungi were recorded for each tree. For pine-oak rust (*Cronartium quercuum* (Berk.) Miyabe) percentage of the main stem encompassed by galls was also recorded. For both the eastern pineshoot borer (*Eucosoma gloriola* Hein.) and the northern pitch twig moth (*Petrova albicapitana* (Busck.)) only leader damage was reported. For the redheaded pine sawfly (*Neodiprion lecontei* (Fitch)) and the white pine weevil (*Pissodes strobi* (Peck)), tree height and the height of the living portion were also measured.

In the early fall of 1978 all the injured trees could be identified as to cause of injury were re-examined. At this time occurrence of pests, probable cause of death, tree form, and diameter were recorded. Each tree was examined for straightness of the first 9 feet of the stem and classified into one of the following four categories: Class 1—trees with relatively straight main stems; Class 2—trees with stem deviations in which any point along a straight line connecting the center of the stem would not fall outside the body of the stem on either side of a crook; Class 3—trees for which points along such a straight line would fall outside the body of the stem; and Class 4—forked or stag-headed trees (Alm and Jensen 1969).

Two factors that could reasonably affect the degree of pest attack were the seed source and the planting site. To sort this out, our analysis was done using categorical methods (Fienberg 1977). For each seed source in each plantation, the number of attacked and nonattacked trees were tabulated. For the pine-oak rust, the 1978 data were included in the analysis. The data were thus in the form of a three-dimensional contingency table, with the factors being: whether or not attacked (2 levels), seed source (30 levels), and block (12 levels). The analysis was based on the model of "no second-order interaction" (Fienberg 1977), which carries the interpretation: "In a group of trees, the ratio of those attacked to those not attacked depends on the seed source of the group and on the site of the group, but the effect of seed source on this ratio is constant from site to site." The explicit form of the model underlying this contingency table analysis can be written:

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$$\log \left(\frac{A_{ij}}{N_{ij}}\right) = K + S_i + B_j,$$

where A_{ij} is the number of trees in group (ij) attacked and N_{ij} is the number not attacked. K is a constant depending on the overall rate of attack, Si_i is the effect due to seed source (i), and B_j is the effect due to block (j). The right-hand side looks exactly like an analysis of variance model, and the usual ANOVA constraints apply:

$$\Sigma S_i = 0, \Sigma B_j = 0.$$

Calculations were done using an iterative proportional fitting program (Fienberg 1977).

Spatial patterns of infestation became evident when the residuals of this initial analysis were plotted on the plantation maps. The blocks were so large that infestation was not uniform, even after allowing for differences due to seed sources. There were "hot spots" of heavy infestation and other areas nearly devoid of infestation in many of the blocks. Therefore, the blocks were redefined as smaller square areas, each containing 4 seed sources (instead of the original 30). Each of these smaller blocks was more realistically described by a single B_j characteristic. Using these 90 blocks instead of the 12 large ones changed the form of the contingency table from "complete" to "incomplete," but the form of the model and the calculation procedure remained as above.

The summary statistics of the model for three pests show the Pearson's statistic is significant for all, indicating that larger than expected residual variability remained (table 1). It would have been surprising if so simple a probability model had fitted such a large data set very well. However, the lack of fit was minor compared with the variability "explained" by the model, and subsequent statistical tests are believed to be reasonable. The lack of fit was spread evenly over data; no residuals were very large, and no spatial or varietal patterns were obvious.

Of greatest importance is the test of whether "real" differences in susceptibility existed in the seed sources (whether one or more of the S_1 are not equal to 0). In all cases, the conditional likelihood ratio statistic, G^2, was highly significant, $p < 0.005$, indicating that the seed sources are **not** all the same in susceptibility. (G^2 is exactly parallel to the F test for treatments in an analysis of variance, except that G^2 is compared to the chi-square distribution rather than the F distribution.)

Similarly, the conditional G^2 for blocks was also highly significant. If the block effect had not been included in the analysis, the categorial analysis would have failed badly. Degree of attack differed considerably from area-to-area, probably due to variation in population density.

An important question is whether the differences among seed sources are consistent from plantation to plantation. A model including the seed source by

Table 1.—*Results of statistical tests for susceptibility to insect and disease pests of jack pine from 30 seed sources from the Lake States*

	Type of injury		
Test	**Eastern pine shoot borer**	**Pine-oak rust**	**Northern pitch twig moth[1]**
Overall fit of model:			
Pearson's statistic	[3]300.1	[3]302.9	[3]226.3
df	241	[2]239	151
Chi-square (0.05)	276.9	274.5	179.6
Test for differences among seed sources (allowing for differences among plots)			
Conditional G^2	77.3	459.8	54.9
df	29	29	29
p level	$<<0.005$	$<<0.005$	≈ 0.005
Test for differences among plots (allowing for differences among seed sources			
Conditional G^2	401.2	769.2	189.2
df	89	89	59
p level	$<<0.005$	$<<0.005$	$<<0.005$
Test for consistency of seed source differences from plantation to plantation			
Conditional G^2	74.1	77.0[f3]	49.3
df	60	60	30
p level	>0.05	>0.05	≈ 0.01

[1] The Pillsbury plantation was omitted from the analysis for the pitch twig moth because this pest was almost absent in this plantation.

[2] Two groups of 16 trees were missing in the Pillsbury plantation in 1978 so the error degrees of freedom were reduced by 2.

[3] Significant at 0.05 level.

plantation interaction was fitted for each pest. This interaction was not significant ($p > 0.05$) for the eastern pineshoot borer or pine-oak rust, but it was for the northern pitch twig moth ($p \approx 0.01$). The consistency of the shoot borer and rust results suggest good predictive value, but the pitch twig moth results are suspect: if they are not consistent between the plantations, we do not know what to expect in future plantings.

To determine the susceptibility of the various sources to attack by the shoot borer, pine-oak rust, and twig moth, the estimates of the S_i parameters of the model were calculated from the fitted values of the contingency table. Rather than listing the S_i, however, we listed $\exp(S_i)$ because the latter have the following intuitive meaning: "If the overall attack rate in the experiment had been 50 percent and if block effects were negligible, the ratio of attacked to nonattacked trees in seed source (i) is estimated by $\exp(S_i)$," referred to below as "susceptibility." One is "average," and the higher it is, the more susceptible the seed source.

Two seed sources are compared by taking the ratio of their susceptibilities. This ratio has the following meaning: "If seed from two sources is planted in a small, uniform area, and if the seed source in the denominator of the ratio is 50 percent infested, the ratio represents the predicted ratio of attacked to nonattacked trees for the other source." This ratio of susceptibilities is also the estimate of the cross product ratio discussed in Fienberg (1977), which is a commonly used measure of association.

How large must this ratio of susceptibilities be to be "significant," that is, for the two seed sources to be considered genuinely "different"? A number of contrasts were computed, testing if seed sources, taken two at a time, were different from each other. The conditional G^2 statistics were plotted against the ratios of susceptibilities (larger over smaller). These points formed a "tight" curve, from which the ratios corresponding to 0.05 and 0.01 levels of the chi-square distribution could be read. These smallest significant ratios are parallel to the least significant differences in an analysis of variance.

RESULTS

Eastern Pineshoot Borer, *Eucosoma gloriola* Hein.

The injury caused by the eastern pineshoot borer is easily identifiable. Infested leaders break off from 2 to 8 mm above the base leaving a flat-topped stub. This injury can cause various degrees of stem crookedness or more rarely forked trees, and often results in trees becoming suppressed.

The infestation rate in the three plantations ranged from 41 to 15 percent (table 2). The average rates of infestation for the individual plantations were 18, 37, and 30 for Cloquet, General Andrews, and Pillsbury, respectively. The percentages of infestation for trees grown from seed collected from each of the three States were 28 for Minnesota, 26 for Wisconsin, and 27 for Michigan.

Trees from the more northerly sources were most susceptible to shoot borer infestation (table 2). To investigate this geographical relation, the logarithms of the susceptibilities were regressed on latitude and longitude of the seed source origins. Only latitude was a significant predictor ($t = 3.197$, $p < 0.005$), the correlation coefficient being 0.53. Susceptibility increased on the average by a factor of

Table 2.—*Susceptibility and infestation rate of jack pine from 30 seed sources to the eastern pineshoot borer*

Seed source (number)	Latitude	Susceptibility[1]	Infestation
	Degrees		*Percent*
1592	47.75	1.81	40
1594	48.03	1.74	38
1621	46.60	1.56	41
1615	46.26	1.52	36
1601	47.48	1.45	34
1593	48.00	1.38	36
1607	45.86	1.34	29
1618	45.00	1.27	29
1613	46.56	1.27	32
1608	45.89	1.25	29
1605	46.75	1.20	31
1604	46.36	1.14	28
1597	47.08	1.11	31
1589	47.00	1.07	30
Local	—	1.05	27
1600	46.75	1.05	30
1595	45.95	1.05	25
1602	47.74	1.03	34
1609	45.28	.94	28
1610	45.75	.93	24
1614	46.20	.91	25
1591	47.55	.80	28
1596	46.30	.76	25
1611	44.45	.76	22
1616	44.26	.64	19
1620	44.52	.60	23
1612	46.22	.58	22
1606	46.02	.56	19
1590	47.34	.56	17
1617	44.34	.47	15

[1] Any two susceptibilities with a ratio (larger over smaller) of less than 1.9 are not significantly different at the 0.05 level.

1.19 for each degree increase in latitude. King (1971) also found a positive correlation between the incidence of attack by the eastern pineshoot borer and latitude in the National Forest plantations he studied. His data show sources 1592 and 1593 from Minnesota and 1615 and 1621 from Michigan to be the most susceptible. These sources along with Minnesota sources 1601 and 1594 were the most most heavily infested in the three Minnesota plantations we investigated. The sources showing the lowest infestation rates were Minnesota sources 1595 and 1590, Wisconsin sources 1609 and 1611, and Michigan sources 1616 and 1617. King's data also show these same sources with low percentages of dead leaders, except source 1611 which had a high percentage of dead leaders in their plantations. In a 20-year study of tree response, Jeffers *et al.* (1980) recorded heights, diameters, and volumes for the various seed sources and found that the sources with the poorest height and diameter growth were the same as those that we found most susceptible to shoot borer injury.

Tree heights and degree of shoot borer infestation were compared for the Cloquet and General Andrews plantations (table 3). Trees between 1.52 and 2.1 meters tall sustained the greatest damage in both plantations. It was unusual to find a tree more than 3 meters tall with an injured leader and little damage occurred during the first 2 years after planting.

Pine-Oak Rust, *Cronartium quercuum* (Berk.) Miyabe

The galls formed on the main stem and branches as the result of pine-oak rust infection are easily distinguishable from other insect and disease damage by their globose form. Another rust on jack pine caused by *Endrocronaitium harknessi* (J. P. Moore) Y. Hiratsuka, which also causes globose galls, does not occur where these plantations are located. The records of infection included the number of stem galls, their height above the ground, and the extent they enveloped the circumference of the tree.

When the seed sources were ranked according to their susceptibility, the highest susceptibility was almost three times greater than the like value obtained from the shoot borer (table 4). The average percentage of trees infected in the three plantations was markedly different—36, 19, and 61, respectively, for Cloquet, General Andrews, and Pillsbury. The average percentage by State of origin was less different—37 for Minnesota, 30 for Wisconsin, and 41 for Michigan.

Table 3.—*Average number of trees infested by the eastern pineshoot borer in the Cloquet and General Andrews Plantations by height*

(In numbers)

CLOQUET PLANTATION

State of seed source	Tree height (meters)				
	0.3-0.88	0.91-1.5	1.52-2.1	2.13-2.71	2.74-3.32
Minnesota	1.5	4.4	5.0	2.5	1.8
Wisconsin	1.0	5.5	5.0	2.0	3.0
Michigan	2.0	3.6	4.7	2.5	1.0
Average	1.5	4.4	5.0	2.5	1.8
GENERAL ANDREWS PLANTATION					
Minnesota	9.6	9.8	13.8	7.5	0
Wisconsin	5.4	9.4	8.7	0	0
Michigan	8.3	8.1	10.7	7.0	0
Average	7.8	9.1	11.1	7.8	0

Table 4.—*Susceptibility and infection rate of jack pine from 30 seed sources to pine-oak rust seed source*

Seed source (number)	Latitude	Longitude	Susceptibility[1]	Infected
	Degrees			Percent
1592	47.75	91.23	5.23	62
1602	47.75	93.28	4.39	60
1621	46.60	85.38	3.66	64
1612	46.22	89.20	3.35	50
1594	48.03	92.42	3.08	57
1593	48.00	90.33	2.67	59
1614	46.26	86.62	2.40	60
1615	46.26	84.84	2.09	54
1610	45.75	89.93	1.83	48
1606	46.02	88.93	1.62	42
1608	45.89	92.03	1.46	40
1613	46.56	89.02	1.36	46
1591	47.55	93.73	1.25	36
1596	46.30	92.93	1.25	38
1601	47.48	95.00	1.15	31
1618	45.00	83.54	.94	31
1617	44.34	84.12	.78	29
1597	47.08	95.47	.73	32
1590	47.34	94.52	.73	27
1607	45.86	89.17	.73	37
1589	47.00	94.00	.63	31
1616	44.26	86.26	.52	15
Local	—	—	.50	25
1605	46.75	90.95	.49	26
1604	46.36	91.73	.49	26
1600	46.75	93.97	.47	22
1620	44.52	85.37	.32	17
1609	45.28	92.55	.23	17
1611	44.45	89.72	.16	6
1595	45.95	92.55	.13	12

[1] Any two susceptibilities with a ratio (larger over smaller) of less than 2.2 are not significantly different at the 0.05 level.

In all three plantations, 1592, 1593, 1594, and 1602 had the highest infection rate among the Minnesota sources. Those with the highest incidence of the rust in sources from Wisconsin were 1610 and 1606, and from Michigan 1621, 1614, and 1615. For the Minnesota sources the least susceptible were 1595 and 1600 with corresponding low ranking for Wisconsin sources 1609 and 1611 and for Michigan sources 1616, 1617, and 1620. Arend *et al.* (1961) found source 1592 highly susceptible, and King (1971) also found Minnesota sources 1594, 1602, 1592, and 1593 most susceptible in that order. These same sources were the most heavily infected in our study. King also found Wisconsin sources 1606 and 1610 with a high rate of infection and 1614, 1615, and 1621 high for Michigan. His data showed that the trees least susceptible to the rust were identical with those in our plantings, 1595 and 1600 from Minnesota, 1609 and 1611 from Wisconsin, and 1610 and 1620 from Michigan. Jeffers and Jensen (1980) stated that sources with the highest rust incidence had the smallest diameters. This is inconsistent with our results because the largest diameter trees in the Pillsbury plantation had the highest infection rate.

The average percentage of pine-oak rust infection was much higher in the Pillsbury plantation than in the other two. This can be explained by the large amount of red oak surrounding the plantation and the fact that pine-oak rust is abundant in this part of Minnesota. Trees grown from seed collected at the most northern latitudes were more susceptible to pine-oak rust (table 4). The validity of this relation was tested by the method described for the eastern pineshoot borer. The overall correlation coefficient was 0.80 ($r^2 = 0.636$) and both latitude and longitude had significant coefficients ($t = 6.68$ and -4.90, respectively, $p < 0.001$). The susceptibility to attack increased with the increase of the latitude of the seed source but decreased with increasing longitude, by a factor of 2.44 for the increase of each degree north, and a factor of 1.228 for each longitude degree to the east. King (1917) also found the northern-most sources with the highest incidence of rust infection. He suggested that the southern sources may have been subjected to more severe selection for resistance, whereas the northern sources, where the alternate red oak host is not as plentiful, may not have been exposed to as much selection pressure.

Because we recorded the extent pine-oak galls encompassed the stems of infected trees, it was possible to relate gall development with the response of infected trees (table 5). Rust-infected trees were categorized by the amount of their stem that was encompassed by galls (either less than 75 percent or more than 75 percent) and by whether they were alive or dead. The numbers were tabulated separately for each seed source. These data were analyzed as a 30x4 contingency table to determine whether the disease progressed the same way in all 30 seed sources, given that all trees were infected. Pearson's statistic was highly significant ($X^2 = 133$ with 87 df, $p < 0.005$), but the lack of fit was due to the small number of observations. Sources 1604, 1617, and 1595 had fewer than average numbers of dead trees with greater than 75 percent of their stem encompassed by galls. Sources 1604 and 1595 had low infection rates. Sources 1621 and 1606 had a greater than average proportion in this class, and source 1594 had a larger than average number of trees that were alive with greater than average proportion of the stem encompassed by galls. These three sources (1621, 1606, and 1594) had been among those with the highest infection rate. Although suggestive, these differences were based on small numbers of trees. Except for these observations, there was no evidence that the 30 seed sources did not behave uniformly with respect to progression of the disease. However, as might be expected, more trees died that had more than 75 percent of the stem encircled by galls. Of the trees with more than 75 percent of the stem encompassed by galls, over-all an average of 93 percent died, while 81 percent with less of the stem encircled lived.

The analysis was repeated with the data categorized by how the gall changed from 1 year to the next: increased in size, decreased in size, remained the same, or closed (table 5). Again, Pearson's statistic was significant($X^2 = 145$ with 87 df, $p < 0.005$), but again the lack of fit was due to a small number of trees. Of greatest interest, sources 1605 and 1608 had a greater than average number of trees with galls that were closed and 1591 had a smaller than average number of trees with galls that increased in size. It should be noted that some of the trees included in these analyses may have died from causes other than rust infection. This would be more likely for the trees with less than 75 percent of the stem encircled by the gall.

The greatest number of pine-oak rust galls for both the General Andrews and the Pillsbury plantations occurred while the trees were less than 1.5 m tall (table 6). The greatest number at the Cloquet plantation occurred when the trees were from 2.25 to 4.57 m tall. The only other notable differences between plantations were the somewhat greater number of taller trees, those ranging from 4.9 to 6.1 meters, infected in the Pillsbury plantation.

Table 5.—*Trees infected with pine-oak rust by size of gall, and change in gall development from year to year (Pillsbury Plantation)*

(In percent)

State of seed source	Amount of stem encompassed by a gall: Less than 75 percent: Alive	Dead	More than 75 percent: Alive	Dead	Annual change in gall encompassed of stem: Increased	Decreased	None	Closed
Minnesota	63	14	2	21	59	15	12	13
Wisconsin	67	13	1	19	59	10	5	17
Michigan	57	20	2	21	63	6	10	11

The Northern Pitch Twig Moth, *Petrova albicapitana* (Busck.)

The northern pitch twig moth forms conspicuous thin-walled pitchy blisters at the base of terminal shoots or at twig crotches under which the larvae feed. This insect has a 2-year life cycle with the most obvious blisters being formed the second year. In all three of our plantations there was only a single brood because second year blisters were found every other year: 1955, 1957, 1959, and 1961. The damage caused by larval feeding may kill terminal twigs including the leader. However, we saw few dead leaders (table 7). In a few cases, the leader was broken over and when the bent leader continued to grow it formed a goose-necked crook.

Table 6.—*Trees infected by pine-oak rust by tree height*

(In numbers)

State of seed source	Tree height (meters): 0-1.5	1.82-3.04	3.35-4.57	4.88-6.09	6.4 +	Total
CLOQUET PLANTATION						
Minnesota	2.8	4.0	19.9	1.2	0	27.8
Wisconsin	2.0	6.0	17.3	0.9	0	26.1
Michigan	2.6	4.3	23.0	1.3	0	31.2
Average	2.5	4.8	20.1	1.1	0.0	28.4
GENERAL ANDREWS PLANTATION						
Minnesota	10.9	2.2	0.5	0.1	0.1	14.1
Wisconsin	5.5	2.1	0.6	0	0	8.5
Michigan	11.7	2.6	1.2	0.4	0	14.4
Average	9.4	2.1	0.8	0.2	0.03	12.3
PILLSBURY PLANTATION						
Minnesota	37.2	4.2	5.5	1.6	0	46.9
Wisconsin	22.2	2.3	4.5	0.5	0	29.7
Michigan	34.8	4.3	9.2	2.6	0	50.8
Average	31.4	3.6	6.4	1.6	0.0	42.5

The analyses to determine the significance of differences in source susceptibility and the relation of latitude to seed source damage were as described for

Table 7.—*Susceptibility and infestation rate of jack pine from 30 seed sources to nothern pitch twig moth (based on only the trees with twig moth blisters on the leaders) at the Cloquet and General Andrews Plantations*

Seed source (number)	Latitude	Susceptibility[1]	Infested
	Degrees		*Percent*
1596	46.30	2.00	66
1600	46.75	1.60	62
1620	44.52	1.56	62
1593	48.00	1.42	58
1607	45.86	1.40	59
1616	44.26	1.28	60
1601	47.48	1.26	53
1618	45.00	1.22	53
1610	45.75	1.20	52
1591	47.55	1.18	55
1613	46.56	1.18	50
1608	45.89	1.10	54
1612	6.22	1.06	55
1597	47.08	1.04	52
1614	46.24	1.02	46
1621	46.60	1.02	43
1605	46.75	1.00	50
1615	46.26	.98	48
1595	45.95	.92	50
1589	47.00	.88	45
1590	47.34	.84	45
1617	44.34	.82	41
1606	46.02	.80	44
1594	48.03	.74	42
1592	47.75	.74	47
1604	46.36	.72	47
1611	44.45	.70	44
1602	47.75	.64	45
1609	45.28	.62	44
Local	—	.50	38

[1] Any two susceptibilities with a ratio (larger over smaller) of less than 1.9 are not significantly different at the 0.05 level.

the other two pests. There were significant differences among seed sources ($p \approx 0.005$), but they were not consistent from plantation to plantation ($p \approx 0.01$) as they were for the eastern pineshoot borer and the pine-oak rust (table 1).

The average percentage of leaders attacked for the sources from each of the three States were almost identical—51, 49, and 51 for Minnesota, Wisconsin, and Michigan, respectively. The sources showing the least susceptibility to twig moth infestation were local (Minnesota), 1609 and 1611 (Wisconsin), and 1617 (Michigan). These same sources also had the lowest percentage of attack by the eastern pineshoot borer and the pine-oak rust, except for the local Minnesota sources. Source susceptibility was not related to latitude or longitude of the source origins for the northern pitch twig moth. King (1971) reported that he found no significant differences among seed sources for this insect in the National Forest plantation he investigated.

Additional Insects

Because of the small number of trees infested by the following insects, we were not able to detect significant results by statistical analysis. Therefore, we will discuss the sources showing only the highest and lowest infestation rates.

The White Pine Weevil, Pissodes strobi *(Peck)*

The greatest number of trees damaged by the white pine weevil were from sources 1595 and 1600 (Minnesota), 1609 and 1611 (Wisconsin), and 1618 and 1620 (Michigan). These sources were among the lowest to be infested by the pine shoot moth and the pine-oak rust. King (1971) also found 1609 and 1611 with a high rate of weeviling and that the five sources with low infestation rates were shorter than average while the four most heavily weeviled sources were taller than average, although the differences are not significant. Batzer (1961) also found sources 1595, 1609, and 1611 to have a high rate of weevil attack. Arend *et al.* (1961) agreed that Wisconsin sources 1609 and 1611 were susceptible to weevil damage. Our data and those of King (1971) show Minnesota 1593, Wisconsin 1606, and Michigan 1621 to be remarkably free of weevil attack.

The Redheaded Pine Sawfly, Neodiprion lecontei *(Fitch)*

The General Andrews Nursery plantation was the only one with many trees that were defoliated by the redheaded pine sawfly. Consequently, our remarks will be based on the infestation in that planting. The sources with by far the highest rate of attack were the local source and Wisconsin source 1606. Arend *et al.* (1961) also found source 1606 to have the highest rate of infestations for trees planted in Michigan's Lower Peninsula. The other sources that were defoliated were 1595 and 1594 from Minnesota, 1604 and 1608 from Wisconsin, and 1612 and 1614 from Michigan. Those showing the least susceptibility to attack were 1589 and 1593, 1611 and 1605, and 1613 and 1621 for Minnesota, Wisconsin, and Michigan, respectively. The heaviest defoliation occurred in 1958 during the fifth summer the trees were in the planting. By the time the canopies had begun to close in 1961, no trees were defoliated by this sawfly.

The Pine Tortoise Scale, Toumyella parvicornis *(Cockerell)*

The General Andrews plantation was the only one significantly damaged by the pine tortoise scale. Of all the seed sources Minnesota source 1595 had the most severe infestation. Others with less injury but with substantial infestation were 1592, 1594, and 1591 (Minnesota), 1606 and 1608 (Wisconsin), and 1613 and 1614 (Michigan). The least infested trees were found in the Minnesota local source, Wisconsin sources 1607 and 1609, and Michigan sources 1615 and 1618.

A Bud Moth, Petrova pallipennis *Mcd.*

The bud moth was not economically important in any of the plantations but did destroy the terminal buds of some trees. The sources with the heaviest infestation were 1592 and 1593 from Minnesota, 1609 from Wisconsin, and 1612 from Michigan.

The Causes of Death

In the fall of 1978 the various causes of individual tree mortality were recorded on the basis of current and past history of damage caused by certain insects, the pine-oak rust fungus, and miscellaneous causes such as porcupine feeding, snow breakage, and windthrow. In only the Pillsbury plantation pocket gophers caused severe losses of 30, 31, and 23 percent for Minnesota, Wisconsin, and Michigan, in that order. Suppression and pine-oak gall infections were the most common causes of death (table 8). For the Minnesota and Michigan sources the gall rust dominated, while for the Wisconsin sources suppression was the cause of most of the mortality. The redheaded pine sawfly killed few trees. The percent mor-

Table 8.—*Estimated cause of death for trees in the three plantations by seed source*
(In percent)

Source number	Cause of death Unknown	Suppression	Eastern pine shoot borer	Pine-oak rust fungus	Redheaded pine sawfly	Miscellaneous[1]
MINNESOTA SOURCES						
1589	18	22	30	20	10	0
1590	49	18	6	19	2	6
1591	33	31	8	25	0	3
1592	23	9	2	62	2	2
1593	35	10	10	43	0	2
1594	21	10	13	44	6	6
1595	33	21	21	10	2	12
1596	29	12	9	32	0	18
1597	31	8	15	35	3	8
1600	32	11	13	13	9	22
1601	15	23	15	39	2	6
1602	26	8	5	54	0	7
Local	39	22	7	12	11 9	
Average	29	16	12	31	4	8
WISCONSIN SOURCES						
1604	65	11	8	8	5	3
1605	39	19	21	9	2	10
1606	55	21	1	14	5	4
1607	37	20	8	18	2	15
1608	35	16	14	23	4	8
1609	47	21	3	15	3	11
1610	44	15	4	30	0	7
1611	45	27	12	6	0	10
Average	46	19	9	15	3	8
MICHIGAN SOURCES						
1612	46	11	3	29	6	5
1613	34	11	6	34	2	13
1614	26	15	13	39	2	5
1615	31	8	8	38	2	13
1616	60	16	8	13	0	3
1617	48	21	7	15	9	0
1618	29	29	6	19	2	15
1620	44	17	7	17	0	15
1621	25	16	2	57	0	0
Average	38	16	7	29	3	7

[1] Miscellaneous causes include porcupine and pocket gopher feeding, snow-breakage, windthrow, etc.

tality due to the eastern pineshoot borer and the pine-oak rust were regressed on the logarithms of the susceptibilities to these pests. The percent of mortality caused by the eastern pineshoot borer was not related to the percent infestation ($r = 0.098$, $p > 0.5$). In sharp contrast the percent mortality caused by the pine-oak rust was significantly related to the percent infection ($r = 0.852$, $p << 0.001$).

Affect of Pest Damage on Average Height Growth, 1958 to 1964

The heights of all trees were measured in 1958 and 1963 in the Cloquet plantation and in 1958 and 1964 at the Pillsbury plantation (table 9). The height

Table 9.—*Average height growth of jack pine from 1958 to 1963 for the Cloquet plantation and from 1958 to 1964 for the Pillsbury plantation as related to pest attach*

(In meters)

State of seed source	Type of pest attack None	Eastern pine shoot borer	Pine-oak rust	Northern pitch twig moth	Whitepine weevil
CLOQUET PLANTATION					
Minnesota	2.8	2.6	2.5	2.8	2.6
Wisconsin	2.7	2.6	2.8	2.8	2.6
Michigan	2.9	2.6	2.7	2.8	2.3
Average	2.8	2.6	2.7	2.8	2.5
PILLSBURY PLANTATION					
Minnesota	3.7	3.3	3.6	3.6	—
Wisconsin	3.8	3.5	3.7	4.0	—
Michigan	3.9	3.5	3.8	—	—
Average	3.8	3.4	3.7	3.8	—

increase of uninfested trees was not significantly different from that of trees attacked by the pine-oak rust fungus and the northern pitch twig moth. For the eastern pine shoot moth and the white pine weevil, however, the differences were significant. The average height increase of shoot borer-damaged trees was 0.2 meter less than that for the pestfree trees at Cloquet and 0.4 meter less at Pillsbury. The weevil-infested trees also grew about 1/3 meter less than the pestfree trees.

Affect of Pest Damage on Average Height Growth, 1958 to 1968

The effects of insect attack and rust infection are somewhat different for ths longer period of time than those presented above (table 10). For all three plantations, trees with leaders killed by the shoot moth had a smaller average height increase than the pestfree trees. The trees infected with pine-oak rust also grew less than those not infected in the Cloquet and Pillsbury plantations. Healthy and infected trees in the General Andrews plantation grew at approximately the same rate. The growth of trees infested by the northern pitch twig moth was consistently greater than that for the pestfree trees, which suggests that this species might have been attracted to the taller trees. Redheaded pine sawfly defoliation caused by far the greatest reduction in height growth, probably because this pest destroys much more than just leaders.

Table 10.—*Average height growth of jack pine from 1958 to 1968 as related to pest damage*

(In meters)

State of seed source	Type of pest attack None	Eastern pine shoot borer	Pine-oak rust	Northern pitch twig moth	Redheaded pine sawfly
CLOQUET PLANTATION					
Minnesota	4.5	4.2	4.0	4.4	—
Wisconsin	4.2	4.4	4.3	4.5	—
Michigan	4.5	4.2	4.3	4.3	—
Average	4.4	4.3	4.2	4.4	—
GENERAL ANDREWS PLANTATION					
Minnesota	5.2	5.0	4.9	5.5	4.7
Wisconsin	5.5	5.3	5.5	5.4	4.9
Michigan	5.4	5.4	5.8	5.5	5.1
Average	5.4	5.3	5.4	5.5	4.9
PILLSBURY PLANTATION					
Minnesota	5.9	5.1	5.7	6.4	4.6
Wisconsin	5.8	5.7	5.6	6.5	—
Michigan	5.9	5.4	5.4	7.4	—
Average	5.9	5.4	5.6	6.8	—
AVERAGE FOR THE THREE PLANTATIONS					
	5.2	5.0	5.1	5.6	—

Affect of Pest Damage on Diameter and Form of Trees

In the fall of 1978 all the living trees in the three plantations were measured for diameter and rated for form (table 11). The average figures for diameter were consistent irrespective of the State from which seed was obtained but trees in the Pillsbury plantation had a greater average diameter. Overall, attack by the eastern pineshoot borer and redheaded pine sawfly caused the greatest reduction in diameter. Trees infected by the pine-oak rust had the same average diameter as noninfected trees.

The form ratings for the three plantations and the seed sources from the three States were remarkably constant. The effect of much earlier infestations by the shoot borer, sawfly, and the weevil is evident by the much higher ratings for all three than for the pestfree trees. As was noted for diameter, the form of trees infected by pine-oak rust was as good as that of noninfected trees.

SUMMARY AND CONCLUSIONS

The susceptibility to attack by insect and disease pests of jack pine grown from seed collected in 13

Table 11.—*Diameter and form of trees in the three plantations as related to pest damages, 1978*

Type of damage	Diameter by plantation			Form rating[1] by plantation		
	Cloquet	Andrews	Pillsbury	Cloquet	Andrews	Pillsbury
MINNESOTA SOURCES						
None	11.4	10.7	13.5	2.0	1.9	2.2
Eastern pine shoot borer	9.9	10.2	13.5	2.5	2.4	2.7
Pine-oak rust	11.4	10.4	14.2	1.9	2.0	2.2
Redheaded pine sawfly	7.9	9.6	—	3.0	2.2	—
White pine weevil	9.6	12.7	—	3.5	3.0	—
WISCONSIN SOURCES						
None	11.9	11.2	12.9	1.9	2.1	2.1
Eastern borer	10.4	10.7	13.4	2.6	2.3	2.6
Pine-oak rust	10.7	11.2	13.4	2.1	1.8	2.2
Redheaded pine sawfly	—	9.4	—	—	2.2	—
White pine weevil	11.4	12.4	11.9	2.9	3.0	3.0
MICHIGAN SOURCES						
None	11.4	10.7	12.9	1.9	2.0	1.9
Eastern pine shoot borer	10.2	10.2	12.7	2.7	2.5	2.7
Pine-oak rust	10.9	10.7	13.7	2.0	1.8	2.3
Redheaded pine sawfly	—	8.6	—	—	2.6	—
White pine weevil	—	13.4	—	—		

[1] Straight-boled trees were rated 1, somewhat crooked trees were rated 2, the crookedest trees were rated 3, and forked and stag-headed trees were rated 4.

Minnesota, 8 Wisconsin, and 9 Michigan localities was investigated in three Minnesota plantations. Significant differences in susceptibility to both insects and fungi were evident among the trees grown from the various seed sources. One striking feature was the high positive correlation between the latitude of sources and the percentage of trees attacked by the eastern pineshoot borer and the pine-oak rust—trees from the northern sources suffered the most severe injury. In sharp contrast and in spite of its common occurrence, the susceptibility of the various seed sources to infestation by the northern pitch twig moth was not affected by latitude.

The seed sources with the highest and lowest incidence of attack by the shoot borer and the rust were almost identical with those reported from similar plantations established in Wisconsin and Michigan. Jeffers and Jensen (1980) found that the northern Minnesota sources, which had the highest gall rust incidence, also exhibited the poorest survival and slowest growth. These sources—1592, 1593, 1594, and 1602—also were among the most severely damaged by the pineshoot borer in the three plantations in our study.

Suppression and infection by the pine-oak rust were by far the most important causes of death in these plantations. Also, the percentage of trees infected by the rust was highly correlated to the mortality caused by this fungus. This was not the case for the eastern pineshoot borer. However, the shoot borer, the white pine weevil, and the redheaded pine sawfly significantly reduced height growth, stem form, and diameter increment of the trees they infested. On the other hand, the growth of trees infested by the northern pitch twig moth was consistently greater than that for pestfree trees.

The occurrence of attack by all of the pest species included in this study was greatest in the early stages of tree growth. The maximum infestation by the shoot borer occurred when the trees were from 1 to 3 meters tall and for the pine-oak rust when the trees were from 1 to 6 meters tall.

The results of this study indicate that it may be difficult to find seed sources of jack pine that would produce trees reasonably free of the many pests that attack this host. For example, the sources that showed the least susceptibility to shoot borer and rust damage were among those with the highest incidence of attack by the white pine weevil, the redheaded pine sawfly, and the pine tortoise scale.

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The susceptibility of jack pine from Lake States seed sources to insects and diseases. Res. Pap. NC-225. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 12 p.

Describes the susceptibility to insect and disease pests of jack pine grown in three Minnesota plantations from seed collected in Minnesota, Wisconsin, and Michigan.

KEY WORDS: Eastern pineshoot borer, pine-oak rust, white pine weevil, redheaded pine sawfly, northern pitch twig moth, jack pine genetics.

North Central Forest Experiment Station
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St. Paul, Minnesota 55108
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North Central Forest Experiment Station

Research Paper **NC-226**

The History and Reliability of the USDA Forest Service Wildfire Report

Linda R. Donoghue

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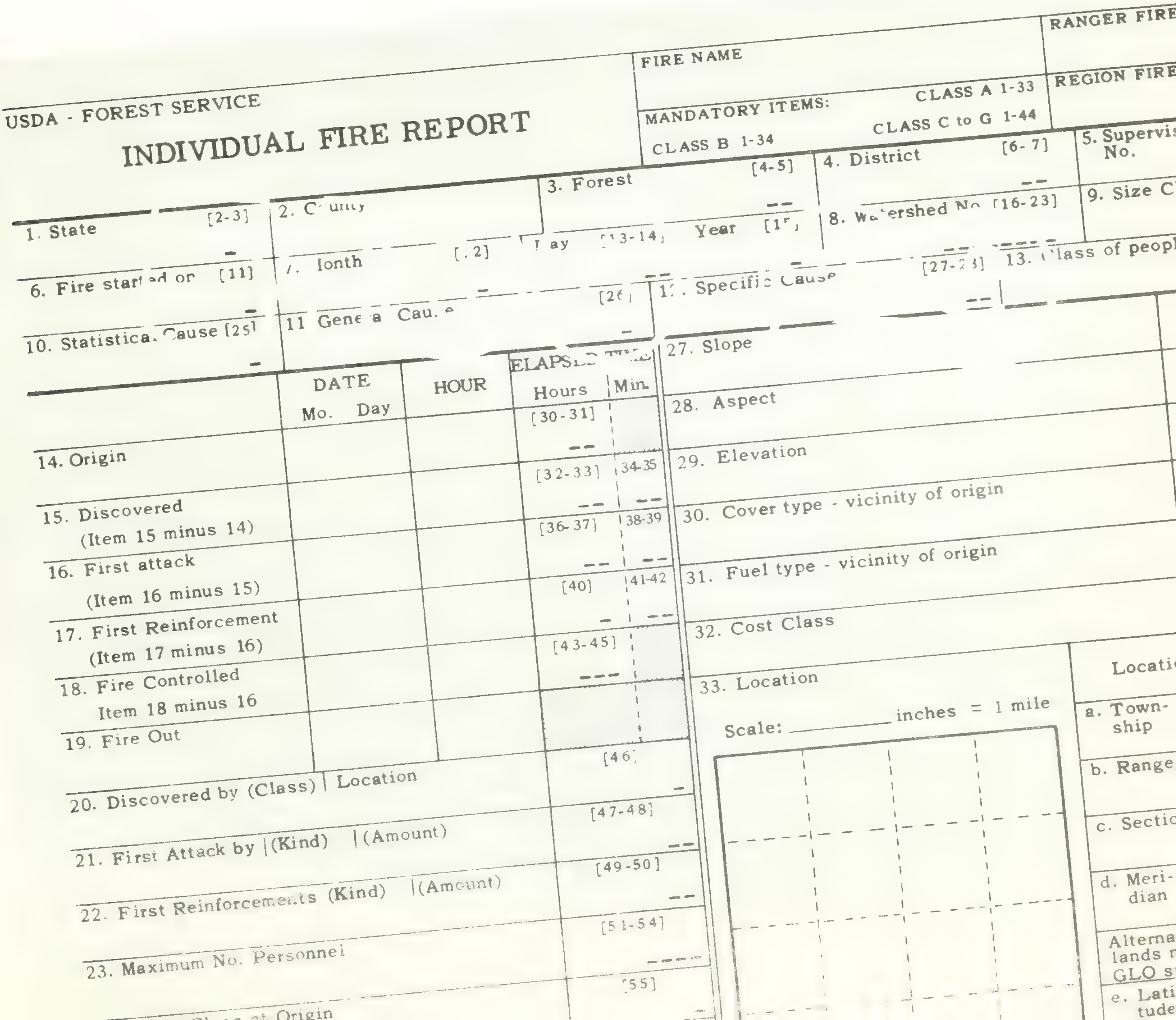

RANGER FIRE

FIRE NAME

REGION FIRE

USDA - FOREST SERVICE

INDIVIDUAL FIRE REPORT

MANDATORY ITEMS: CLASS A 1-33

CLASS B 1-34

CLASS C to G 1-44

1. State [2-3]

2. County

3. Forest [4-5]

4. District [6-7]

5. Supervis No.

6. Fire started on [11]

7. Month [12]

Day [13-14]

Year [15]

8. Watershed No. [16-23]

9. Size C

10. Statistical Cause [25]

11 General Cause [26]

12. Specific Cause [27-28]

13. Class of peopl

	DATE Mo. Day	HOUR	ELAPSED TIME Hours	Min.
14. Origin			[30-31]	
15. Discovered (Item 15 minus 14)			[32-33]	34-35
16. First attack (Item 16 minus 15)			[36-37]	38-39
17. First Reinforcement (Item 17 minus 16)			[40]	41-42
18. Fire Controlled Item 18 minus 16			[43-45]	
19. Fire Out				

20. Discovered by (Class) | Location [46]

21. First Attack by | (Kind) | (Amount) [47-48]

22. First Reinforcements (Kind) | (Amount) [49-50]

23. Maximum No. Personnel [51-54]

[55]

Class at Origin

27. Slope

28. Aspect

29. Elevation

30. Cover type - vicinity of origin

31. Fuel type - vicinity of origin

32. Cost Class

33. Location

Scale: ________ inches = 1 mile

Locati

a. Town-ship

b. Range

c. Sectio

d. Meri-dian

Alterna lands n GLO s

e. Lati tude

ACKNOWLEDGMENTS

I offer special thanks to my co-workers, Donald A. Haines, William A. Main, and John S. Frost, for their support and assistance during the course of this study. I especially appreciate their helpful comments and suggestions, their computer and statistical support, and their willingness to accompany me on the long and often tiring trips to 62 Ranger Districts in Region-9.

I'm also grateful to Douglas Helms who so graciously and cheerfully helped me locate historical Forest Service fire reports in the National Archives Building, Washington, D.C., and finally to Forest Service District personnel, for their enthusiasm, unceasing support, and cooperation during my visits to their home territory. I hope this study can, in some way, make their jobs a little easier.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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THE HISTORY AND RELIABILITY OF THE USDA FOREST SERVICE WILDFIRE REPORTS

Linda R. Donoghue, *Research Forester,*
East Lansing, Michigan

Wildfire reporting is as old as the USDA Forest Service. Beginning in 1905 with Form 944, fire information has been reported in varying detail under several different formats. This paper briefly traces the history of Forest Service fire report forms, examines both the quantity and quality of information recorded on the current Individual Fire Report, Form 5100-29, and discusses other aspects of the Forest Service wildfire reporting system. This information will be useful to those evaluating and designing wildfire reporting systems. By viewing the patterns of historical development and change that led to the current 5100-29, and by examining factors influencing the quality of data recorded on the form, land managers will have a good foundation on which to base their decisions to change the Forest Service wildfire reporting system.

FIRE REPORT HISTORY

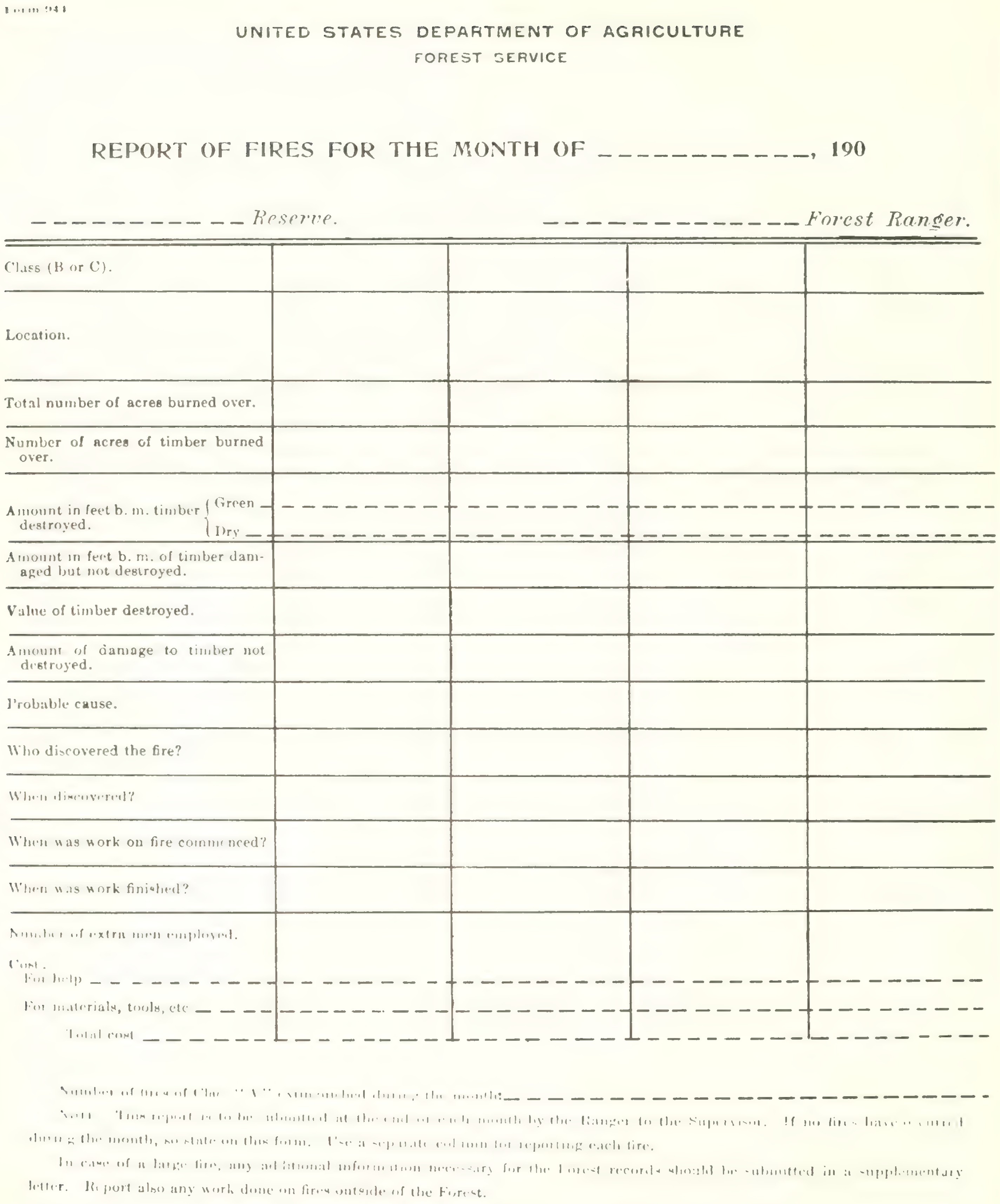
The first Forest Service fire report (Form 944)[1], issued in 1905, required only 15 items of information for each Class B or C[2] fire recorded (fig. 1). Unlike subsequent forms, this initial report had space to report up to four individual wildfires. By 1914 a pocket-size report (Form 874-6) was used to record an individual fire in any size class. Compared to the original form, a more detailed accounting, particularly of suppression costs, acres burned, and timber damage, was required for each wildfire. Although Form 874-6 was probably the first individual fire report (i.e., only one fire was reported per form), Form 929, issued around 1920, was the first to receive the official title **Individual Fire Report** used to this day. Beginning in the 1920's, the information required about a single wildfire increased considerably; form size expanded from 3½ by 6¼ inches in 1914 to 8 by 14 inches in 1920 and to 8 by 16 inches in 1931 (fig. 2). During the 1920's, up to four different individual fire reports were used Forest Servicewide; they were identical except for supplemental fire information recorded under the heading "Studies." Apparently, different research data were recorded for different Forest Service Regions to assess fire-danger in specific areas of the country. In the 1930's "Studies" was replaced with a detailed "Analysis of Action Taken" at the fire scene. This latter supplemental information was primarily responsible for the increased size of the 1930 reports. By this time, too, all of the regions reported the same information on a standardized 929 form, but the amount of information reported depended on the size of the fire. One 929 was required for Class B and C fires and perhaps a different form for Class A fires, although there's no historical record of a Class A fire report.

1940 marked the modern era of fire reporting. The report form issued at this time was the first designed for automated data processing and easy readability (fig. 3). The standard 8- by 10½-inch form was initially used to report all size classes of fires. By 1946, "A" fires were officially reported on a separate form. Beginning in 1950, the amount of information required for wildfires was gradually reduced, and all size classes were reported on one form. The current fire report, containing 44 items, is basically a condensed version of the 1960 form (fig. 4a, 4b).

---

[1] *Fire report forms and related correspondence issued by the Forest Service from 1905 to 1959 were obtained from the National Archives Building; Records of the Forest Service (Record Group 95); Records of the Division of Operation (1900-44) and Division of Fire Control (1909-41); Office Copies of Forms (1900-09), Records of the Office of Forest Reserves (1905-7), General Correspondence (1909-37), and Statistical Data (1935-41).*

[2] *Only three fire-size classes were initially reported: Class A (under ¼ acre); Class B (under 10 acres); and Class C (over 10 acres). Apparently no information was reported for Class A fires other than the total number for each month.*



Form 944

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

REPORT OF FIRES FOR THE MONTH OF ____________, 190

______________ *Reserve.* ______________ *Forest Ranger.*

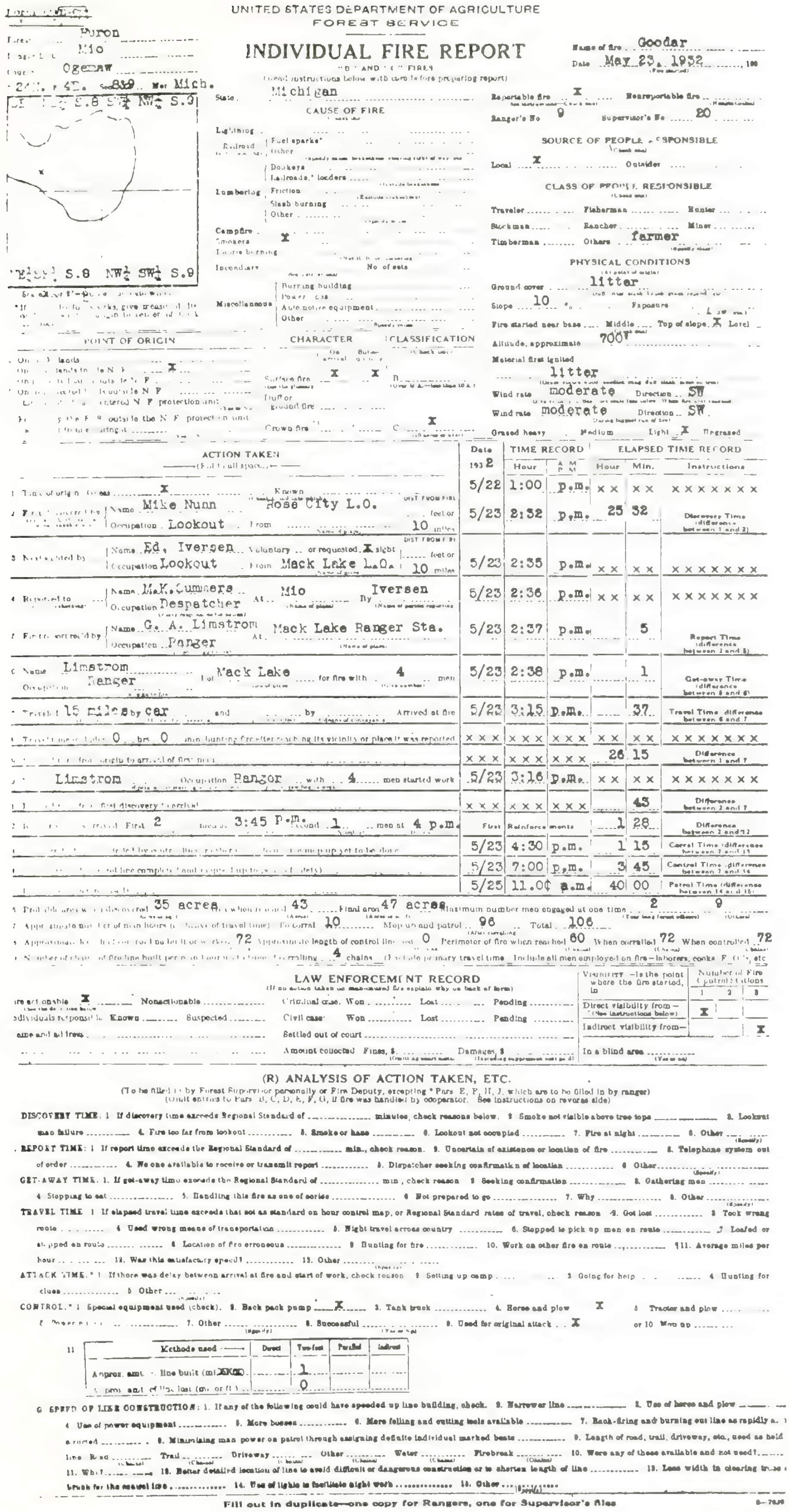
Class (B or C).				
Location.				
Total number of acres burned over.				
Number of acres of timber burned over.				
Amount in feet b. m. timber destroyed. Green				
Amount in feet b. m. timber destroyed. Dry				
Amount in feet b. m. of timber damaged but not destroyed.				
Value of timber destroyed.				
Amount of damage to timber not destroyed.				
Probable cause.				
Who discovered the fire?				
When discovered?				
When was work on fire commenced?				
When was work finished?				
Number of extra men employed.				
Cost. For help				
For materials, tools, etc				
Total cost				

Number of fires of Class "A" extinguished during the month: ______________

NOTE.—This report is to be submitted at the end of each month by the Ranger to the Supervisor. If no fires have occurred during the month, so state on this form. Use a separate column for reporting each fire.

In case of a large fire, any additional information necessary for the Forest records should be submitted in a supplementary letter. Report also any work done on fires outside of the Forest.

Figure 1.—*Form 944—the first USDA Forest Service fire report form.*



UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INDIVIDUAL FIRE REPORT
"B" AND "C" FIRES

Forest Huron
Mio
Ogemaw
24N. R 4E. Sec. 8-9 Mer Mich.
S.8 SW¼ NW¼ S.9
E½ SE¼ S.8 NW¼ SW¼ S.9

Name of fire Goodar
Date May 23, 1932
State Michigan
Reportable fire X Nonreportable fire
Ranger's No 9 Supervisor's No 20

CAUSE OF FIRE

Lightning
Railroad: Fuel sparks; Other
Lumbering: Donkeys; Railroads, loaders; Friction; Slash burning; Other
Campfire
Smokers X
Debris burning
Incendiary — No. of sets
Miscellaneous: Burning building; Power line; Automotive equipment; Other

SOURCE OF PEOPLE RESPONSIBLE

Local X Outsider

CLASS OF PEOPLE RESPONSIBLE

Traveler Fisherman Hunter
Stockman Rancher Miner
Timberman Others farmer

PHYSICAL CONDITIONS

Ground cover litter
Slope 10 % Exposure
Fire started near base Middle Top of slope X Level
Altitude, approximate 700'
Material first ignited litter
Wind rate moderate Direction SW
Wind rate moderate Direction SW
Grazed heavy Medium Light X Ungrazed

POINT OF ORIGIN

X

CHARACTER — CLASSIFICATION

Surface fire X X
Duff or ground fire
Crown fire
C X

ACTION TAKEN

	Date 1932	Hour	A.M. P.M.	Elapsed Hour	Elapsed Min.	Instructions
1 Time of origin: Guess X Known	5/22	1:00	p.m.	x x	x x	x x x x x x x
2 First discovered by: Name Mike Nunn, Rose City L.O.; Occupation Lookout; 10 miles	5/23	2:32	p.m.	25	32	Discovery Time (difference between 1 and 2)
3 Name Ed. Iversen; Voluntary or requested X sight; Occupation Lookout; From Mack Lake L.O.; 10 miles	5/23	2:35	p.m.	x x	x x	x x x x x x x
4 Reported to: Name M.K. Cummers; Occupation Despatcher; At Mio; By Iversen	5/23	2:36	p.m.	x x	x x	x x x x x x x
5 Fire report rec'd by: Name G. A. Limstrom; Occupation Ranger; At Mack Lake Ranger Sta.	5/23	2:37	p.m.		5	Report Time (difference between 2 and 5)
6 Name Limstrom; Occupation Ranger; Left Mack Lake for fire with 4 men	5/23	2:38	p.m.		1	Get-away Time (difference between 5 and 6)
7 Traveled 15 miles by car; Arrived at fire	5/23	3:15	p.m.		37	Travel Time, difference between 6 and 7
8 Travel time … 0 hrs 0 min hunting fire after reaching its vicinity or place it was reported	x x x	x x x	x x x	x x	x x	x x x x x x x
9 … from origin to arrival of first men	x x x	x x x	x x x	26	15	Difference between 1 and 7
10 Limstrom; Occupation Ranger; with 4 men started work	5/23	3:16	p.m.	x x	x x	x x x x x x x
11 … first discovery to arrival	x x x	x x x	x x x		45	Difference between 2 and 7
12 … First 2 … 3:45 p.m. Second 1 men at 4 p.m.	First	Reinforcements		1	28	Difference between 2 and 12
13	5/23	4:30	p.m.	1	15	Corral Time (difference between 7 and 13)
14	5/23	7:00	p.m.	3	45	Control Time (difference between 7 and 14)
15	5/25	11.00	a.m.	40	00	Patrol Time (difference between 14 and 15)

16 … 35 acres … 43 … Final area 47 acres. Maximum number men engaged at one time 2 … 9
17 … To corral 10 … Mop-up and patrol 96 … Total 106
18 … 72 … Approximate length of control line lost 0 Perimeter of fire when reached 60 When corralled 72 When controlled 72
19 … 4 chains … Include all men employed on fire—laborers, cooks, etc.

LAW ENFORCEMENT RECORD
(If no action taken on man-caused fire explain why on back of form)

Fire actionable X Nonactionable
Individuals responsible: Known Suspected
Name and address
Criminal case. Won Lost Pending
Civil case: Won Lost Pending
Settled out of court
Amount collected Fines, $ Damages, $

Visibility—Is the point where the fire started, in	1	2	3
Direct visibility from—	X		
Indirect visibility from—			X
In a blind area			

(R) ANALYSIS OF ACTION TAKEN, ETC.
(To be filled in by Forest Supervisor personally or Fire Deputy, excepting * Pars. E, F, H, J, which are to be filled in by ranger)
(Omit entries to Pars. B, C, D, E, F, G, if fire was handled by cooperator. See instructions on reverse side)

DISCOVERY TIME. 1. If discovery time exceeds Regional Standard of .... minutes, check reasons below. 2. Smoke not visible above tree tops .... 3. Lookout man failure .... 4. Fire too far from lookout .... 5. Smoke or haze .... 6. Lookout not occupied .... 7. Fire at night .... 8. Other ....

REPORT TIME: 1. If report time exceeds the Regional Standard of .... min., check reason. 2. Uncertain of existence or location of fire .... 3. Telephone system out of order .... 4. No one available to receive or transmit report .... 5. Dispatcher seeking confirmation of location .... 6. Other ....

GET-AWAY TIME. 1. If get-away time exceeds the Regional Standard of .... min., check reason. 2. Seeking confirmation .... 3. Gathering men .... 4. Stopping to eat .... 5. Handling this fire as one of series .... 6. Not prepared to go .... 7. Why .... 8. Other ....

TRAVEL TIME. 1. If elapsed travel time exceeds that set as standard on hour control map, or Regional Standard rates of travel, check reason. 2. Got lost .... 3. Took wrong route .... 4. Used wrong means of transportation .... 5. Night travel across country .... 6. Stopped to pick up men en route .... 7. Loafed or stopped en route .... 8. Location of fire erroneous .... 9. Hunting for fire .... 10. Work on other fire en route .... 11. Average miles per hour .... 12. Was this satisfactory speed? .... 13. Other ....

ATTACK TIME.* 1. If there was delay between arrival at fire and start of work, check reason. 2. Setting up camp .... 3. Going for help .... 4. Hunting for clues .... 5. Other ....

CONTROL.* 1. Special equipment used (check). 2. Back pack pump X 3. Tank truck .... 4. Horse and plow X 5. Tractor and plow .... 6. Power pump .... 7. Other .... 8. Successful .... 9. Used for original attack X or 10. Mop up ....

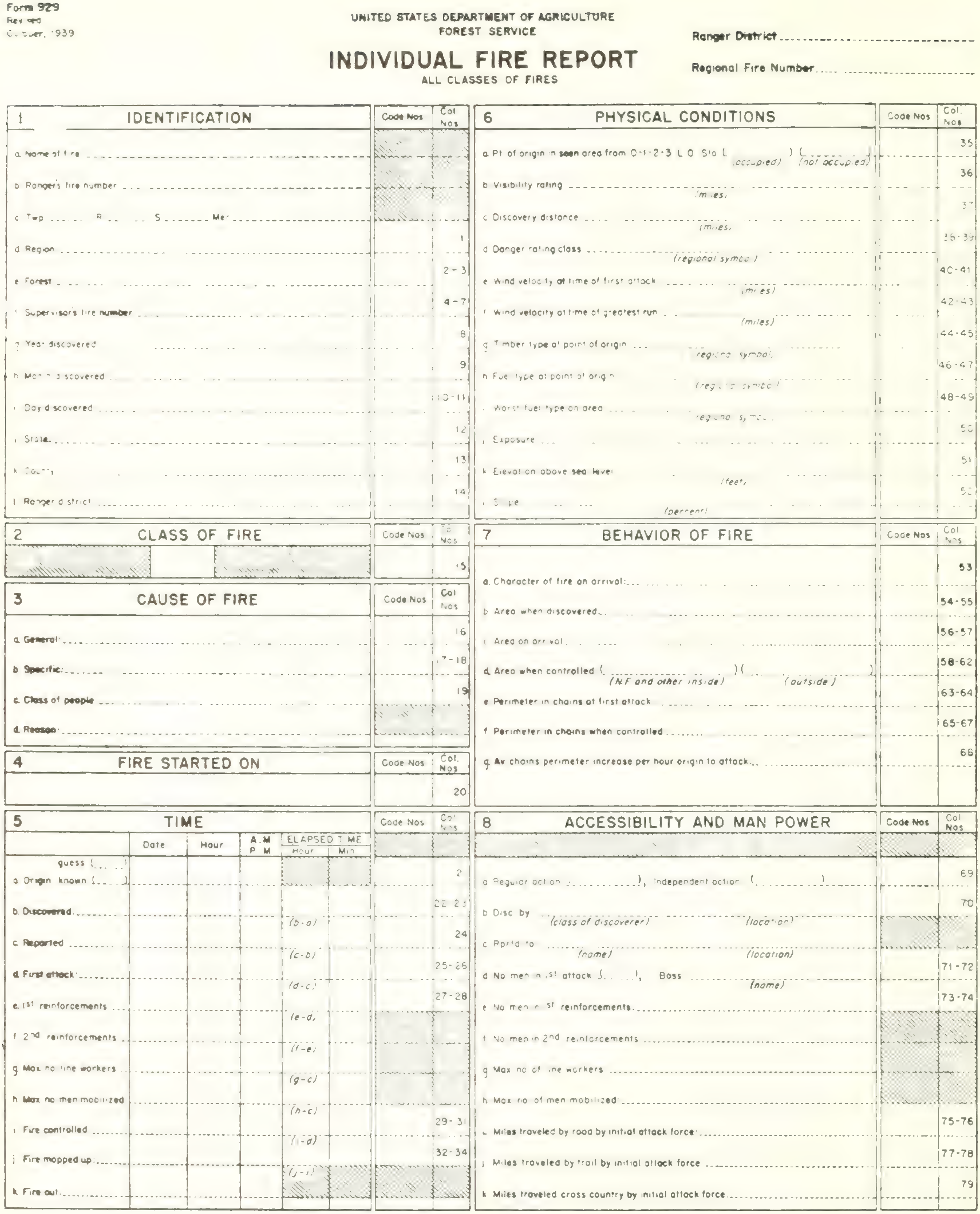
11

Methods used	Direct	Two-foot	Parallel	Indirect
Approx. amt. of line built (mi. or ch.)		1		
Approx. amt. of line lost (mi. or ft.)		0		

G. SPEED OF LINE CONSTRUCTION: 1. If any of the following could have speeded up line building, check. 2. Narrower line .... 3. Use of horse and plow .... 4. Use of power equipment .... 5. More bosses .... 6. More felling and cutting tools available .... 7. Back-firing and burning out line as rapidly as constructed .... 8. Minimizing man power on patrol through assigning definite individual marked beats .... 9. Length of road, trail, driveway, etc., used as hold line. Road .... Trail .... Driveway .... Other .... Water .... Firebreak .... 10. Were any of these available and not used? .... 11. Why? .... 12. Better detailed location of line to avoid difficult or dangerous construction or to shorten length of line .... 13. Less width in clearing trash and brush for the actual line .... 14. Use of lights to facilitate night work .... 15. Other ....

Fill out in duplicate—one copy for Rangers, one for Supervisor's files

Figure 2.—*Front of the Forest Service Individual Fire Report, Form 929, used for Class B and C fires during the 1930's. Up to 700 entries were possible on this 8- x 16-inch form.*



Form 929
Revised
October, 1939

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INDIVIDUAL FIRE REPORT
ALL CLASSES OF FIRES

Ranger District ______________

Regional Fire Number ______________

1 IDENTIFICATION	Code Nos	Col Nos
a. Name of fire ______	▨	▨
b. Ranger's fire number ______	▨	▨
c. Twp ____ R ____ S ____ Mer ______	▨	▨
d. Region ______		1
e. Forest ______		2-3
f. Supervisor's fire number ______		4-7
g. Year discovered ______		8
h. Month discovered ______		9
i. Day discovered ______		10-11
j. State ______		12
k. County ______		13
l. Ranger district ______		14

2 CLASS OF FIRE			Code Nos	Col Nos
▨		▨		15

3 CAUSE OF FIRE	Code Nos	Col Nos
a. General: ______		16
b. Specific: ______		17-18
c. Class of people ______		19
d. Reason: ______	▨	▨

4 FIRE STARTED ON	Code Nos	Col. Nos
		20

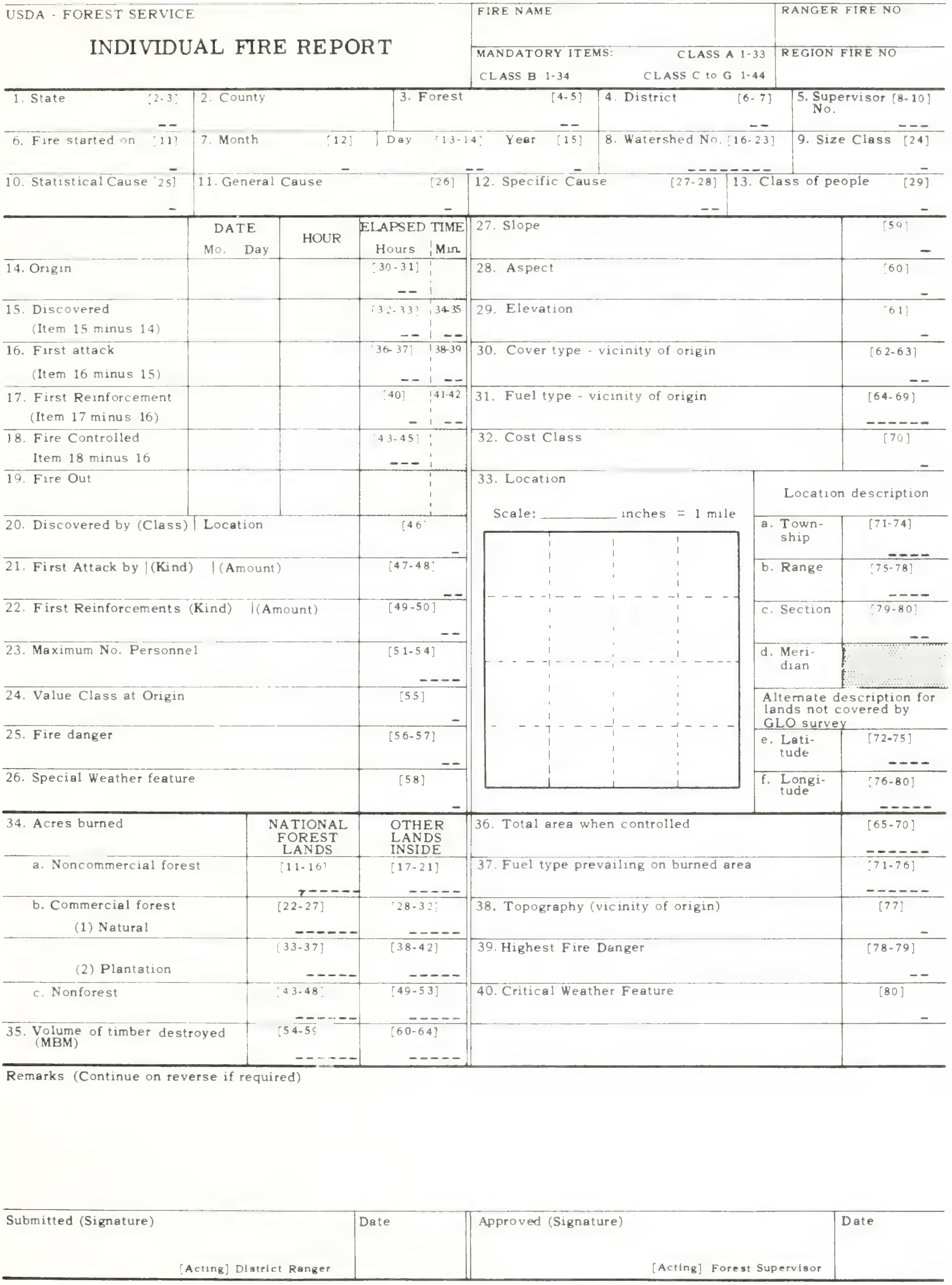
5 TIME						Code Nos	Col Nos
	Date	Hour	A.M. P.M.	ELAPSED TIME Hour	ELAPSED TIME Min	▨	▨
a. Origin guess (____) known (____)				▨	▨		2
b. Discovered ______				(b-a)			22-23
c. Reported ______				(c-b)			24
d. First attack: ______				(d-c)			25-26
e. 1st reinforcements ______				(e-d)			27-28
f. 2nd reinforcements ______				(f-e)		▨	▨
g. Max. no. line workers ______				(g-c)		▨	▨
h. Max. no. men mobilized ______				(h-c)			
i. Fire controlled ______				(i-d)			29-31
j. Fire mopped up: ______				(j-i)			32-34
k. Fire out ______				▨	▨	▨	▨

6 PHYSICAL CONDITIONS	Code Nos	Col. Nos
a. Pt. of origin in seen area from 0-1-2-3 L.O. Sta. (______) (______) (occupied) (not occupied)		35
b. Visibility rating ______ (miles)		36
c. Discovery distance ______ (miles)		37
d. Danger rating class ______ (regional symbol)		38-39
e. Wind velocity at time of first attack ______ (miles)		40-41
f. Wind velocity at time of greatest run ______ (miles)		42-43
g. Timber type at point of origin ______ (regional symbol)		44-45
h. Fuel type at point of origin ______ (regional symbol)		46-47
i. Worst fuel type on area ______ (regional symbol)		48-49
j. Exposure ______		50
k. Elevation above sea level ______ (feet)		51
l. Slope ______ (percent)		52

7 BEHAVIOR OF FIRE	Code Nos	Col Nos
a. Character of fire on arrival: ______		53
b. Area when discovered ______		54-55
c. Area on arrival ______		56-57
d. Area when controlled (______) (______) (N.F. and other inside) (outside)		58-62
e. Perimeter in chains at first attack ______		63-64
f. Perimeter in chains when controlled ______		65-67
g. Av. chains perimeter increase per hour origin to attack ______		66

8 ACCESSIBILITY AND MAN POWER	Code Nos	Col Nos
▨	▨	▨
a. Regular action (______), Independent action (______)		69
b. Disc. by ______ (class of discoverer) ______ (location)		70
c. Rpt'd to ______ (name) ______ (location)	▨	▨
d. No. men in 1st attack (____), Boss ______ (name)		71-72
e. No. men in 1st reinforcements ______		73-74
f. No. men in 2nd reinforcements ______	▨	▨
g. Max. no. of line workers ______	▨	▨
h. Max. no. of men mobilized: ______	▨	▨
i. Miles traveled by road by initial attack force: ______		75-76
j. Miles traveled by trail by initial attack force ______		77-78
k. Miles traveled cross country by initial attack force ______		79

Figure 3.—*Front of the 1940 Forest Service Individual Fire Report, Form 929. This was the first form designed for automated data processing.*



USDA - FOREST SERVICE

INDIVIDUAL FIRE REPORT

FIRE NAME		RANGER FIRE NO
MANDATORY ITEMS: CLASS A 1-33 CLASS B 1-34 CLASS C to G 1-44		REGION FIRE NO

1. State [2-3]	2. County	3. Forest [4-5]	4. District [6-7]	5. Supervisor No. [8-10]
6. Fire started on [11]	7. Month [12] | Day [13-14] Year [15]		8. Watershed No. [16-23]	9. Size Class [24]
10. Statistical Cause [25]	11. General Cause [26]	12. Specific Cause [27-28]	13. Class of people [29]	

	DATE Mo. Day	HOUR	ELAPSED TIME Hours	Min.
14. Origin			[30-31]	
15. Discovered (Item 15 minus 14)			[32-33]	34-35
16. First attack (Item 16 minus 15)			[36-37]	38-39
17. First Reinforcement (Item 17 minus 16)			[40]	41-42
18. Fire Controlled Item 18 minus 16			[43-45]	
19. Fire Out				

20. Discovered by (Class) | Location	[46]
21. First Attack by |(Kind) |(Amount)	[47-48]
22. First Reinforcements (Kind) |(Amount)	[49-50]
23. Maximum No. Personnel	[51-54]
24. Value Class at Origin	[55]
25. Fire danger	[56-57]
26. Special Weather feature	[58]

27. Slope	[59]
28. Aspect	[60]
29. Elevation	[61]
30. Cover type - vicinity of origin	[62-63]
31. Fuel type - vicinity of origin	[64-69]
32. Cost Class	[70]

33. Location

Scale: __________ inches = 1 mile

Location description

a. Township	[71-74]
b. Range	[75-78]
c. Section	[79-80]
d. Meridian	

Alternate description for lands not covered by GLO survey

e. Latitude	[72-75]
f. Longitude	[76-80]

34. Acres burned	NATIONAL FOREST LANDS	OTHER LANDS INSIDE
a. Noncommercial forest	[11-16]	[17-21]
b. Commercial forest (1) Natural	[22-27]	[28-32]
(2) Plantation	[33-37]	[38-42]
c. Nonforest	[43-48]	[49-53]
35. Volume of timber destroyed (MBM)	[54-59	[60-64]

36. Total area when controlled	[65-70]
37. Fuel type prevailing on burned area	[71-76]
38. Topography (vicinity of origin)	[77]
39. Highest Fire Danger	[78-79]
40. Critical Weather Feature	[80]

Remarks (Continue on reverse if required)

Submitted (Signature) [Acting] District Ranger	Date	Approved (Signature) [Acting] Forest Supervisor	Date

5100-29 (10/69)

Figure 4a.—*Front of the 1970 Forest Service Individual Fire Report, Form 5100-29.*

Value of Resources Damaged or Destroyed (Code in hundreds of dollars)		N.F. LANDS (1)		OTHER LANDS (2) INSIDE FS PROTECTION	
		Dollars	Code	Dollars	Code
41. Timber			[11-15] -----		[16-20] -----
42. Other (non-timber)					
a. Watershed			[21-25] -----		[26-29] ----
b. Recreation			[30-34] -----		[35-38] ----
c. Range & Wildlife					
d. Improvements					
e. Other non-timber					
f. Total non-timber (a to e incl.)			[39-43] -----		[44-48] -----
43. GRAND TOTAL (Items 41 and 42f)					
44. Acres burned by Value Class	Value Class		Acres		Acres
	[49] _		[50-54] -----		[55-59] -----
	[60] _		[61-65] -----		[66-70] -----
	[71] _		[72-75] ----		[76-79] ----

GPO 888-978

Figure 4b.—*Back of the 1970 Forest Service Individual Fire Report, Form 5100-29.*

Table 1.—*Fire location items reported on USDA Forest Service fire reports from 1905 to 1981*

Fire location	**1905-1909**	**1910-1919**	**1920-1929**	**1930-1939**	**1940-1949**	**1950-1959**	**1960-1969**	**1970-1981**
State			X	X	X	X	X	X
County			X	X	X	X	X	X
Region			X		X	X		
Forest	X	X	X	X	X	X	X	X
District			X	X	X	X	X	X
Sec.-Twp.-Range			X	X	X	X	X	X
Latitude-Longitude							X	X
Map			X	X	X	X	X	X
At Discovery[1]		X	X	X	X	X	X	X

[1]This refers to land either inside or outside Forest Service protection boundaries.

In addition to fluctuations in report size, changes in titles and form numbers and other modifications since 1905, fire report content has also been revised. Basically, 14 general categories of fire information have been reported fairly consistently: fire name, fire number, location, size class, cause, date started or discovered, fire occurrence and suppression times, environmental conditions, fire behavior and size increase, suppression forces and activities, acres burned, fire damages, remarks, and signature(s) of officer(s) approving a report. Within most of these categories the kind and amount of information reported changed from decade to decade. Table 1, for instance, shows the range of fire location items reported from 1905 to the present. Initially, a simple written description was used (e.g., "2½ miles Northwest of Goodells Creek Bridge"), but as more detailed and accurate reporting became necessary, the amount of required fire-location information increased.

Fire-cause classifications were also expanded over the years to identify in greater detail the primary causes of wildfires and the persons responsible for them. Because these cause categories have been treated separately in another paper, their historical development and use will not be discussed.[3]

To gauge the efficiency and, in part, the effectiveness of suppression efforts, the times at which various fire activities occurred were documented on wildfire reports (table 2). Fire times reported with the greatest frequency from decade to decade include origin, discovery, reported, first attack, reinforcements, control, and fire mopped up and/or out. Information such as who discovered the fire, who reported it, or who received the report accompanied the time data during most of the report's history. Although 20 different categories of elapsed times, calculated from fire occurrence and suppression times, have been used since 1920, no more than 12 were documented on a fire report in any given decade. As fire control activities became increasingly organized and complex, managers needed more information to assess fire behavior. As a result, beginning in 1920, environmental conditions such as cover and fuel types, fire-danger indicators, weather, and topography were incorporated on individual fire reports (table 3). Slope, aspect, and elevation were reported continuously for 60 years.

In conjunction with environmental conditions, fire behavior and fire size at various stages of suppression were reported (table 4). This information enabled fire control managers to gauge the efficiency of their suppression efforts and predict when such efforts would be required.

The number and type of suppression forces used on a wildfire, the quantity of suppression effort (work-hours) required, achievements (measured in terms of line construction), costs, and other related data have been documented to some degree on fire reports since 1905 (table 5). Items most commonly reported include number of people at first attack, the number of reinforcements, total number of workers, and fire suppression costs. By 1970, work-hour and line construction data were no longer reported.

Reporting acreage burned and fire damages grew into a complex process over the years, particularly in the 1920's and 1930's. In 1905, for example, only acres of timber and the total area burned were documented. By 1930, however, the report also included acreages of nonproductive forest, mature or merchantable timber, reproduction or young growth, cutover areas and slash, stocked and unstocked miscellaneous areas, livestock forage, complete kill in

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[3]*See Donoghue, Linda R. Classifying wildfire causes in the USDA Forest Service: problems and alternatives. Res. Note NC-280. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 5 p.*

Table 2.—*Fire occurrence and suppression times reported on USDA Forest Service fire reports from 1905 to 1981*

Fire occurrence and suppression times (Date/hour/minute)	1905-1909[1]	1910-1919	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1981
Origin			X	X	X	X	X	X
Discovery	X	X	X	X	X	X	X	X
Reported		X	X	X	X	X	X	
Departed			X	X			X	
Arrival			X	X				
First attack	X	X	X	X	X	X	X	X
Reinforcements			X	X	X	X	X	X
Fire corralled				X				
Fire controlled			X	X	X	X	X	X
Fire mopped up/out	X	X	X	X	X	X	X	X
Time when maximum number of workers were on the line					X			
Time when maximum number of workers were mobilized					X			

[1]Only the date was reported.

each timber type, and acres burned due to avoidable errors in fire control methods. All this information was required for each major timber type in which the fire occurred on National Forest land, other lands inside the forest, and protected and unprotected lands outside the forest boundary. Similarly, damage information increased from the amount and value of timber destroyed to include quantity and value of other resources lost to a wildfire. Although the content and format of this information changed from decade to decade, some patterns do emerge:

- Generally, acreage and damage information was recorded in tabular form with ownership categories (e.g., National Forest land, private lands inside, outside lands protected or unprotected) on one axis and resource categories (e.g., timber, range, wildlife, recreation) on the other.

- Acreage burned was divided primarily into commercial, noncommercial, nonforest, and young-growth or reproduction land categories.

- Damages were divided into two basic categories, timber and nontimber, with the former receiving the greatest emphasis, particularly from 1905-1940. During that time, detailed accountings of damages to forest land and plant growth under different stages of development were required. The amount of rangeland burned was the only nontimber resource given major recognition.

Table 3.—*Environmental conditions reported on USDA Forest Service fire reports from 1905 to 1981*

Environmental conditions	1905-1909[1]	1910-1919[1]	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1981
Cover and fuel types								
Cover type-origin					X	X	X	X
Cover type-prevailing							X	
Fuel type-origin			X	X	X			X
Fuel type-prevailing						X	X	X
Worst fuel type					X			
Specific fuel-origin/spread			X	X		X	X	
Fire-danger & weather								
Fire-danger rating classes or indices					X	X	X	X
Windspeed			X	X	X	X		X
Topography								
Vicinity of origin/ placement on slope				X			X	X
Slope			X	X	X	X	X	X
Aspect/exposure			X	X	X	X	X	X
Elevation			X	X	X	X	X	X

[1]Not reported.

Table 4.—*Measures of fire behavior and size increase reported on USDA Forest Service fire reports from 1905 to 1981*

Measures of fire behavior and size increase	1905-1909[1]	1910-1919[1]	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1981
Fire behavior								
Character of fire on arrival			X	X	X	X	X	
Rate-of-spread							X	
Fire-size increase								
Area when discovered			X	X	X	X	X	
Area on arrival/attack			X	X	X	X	X	
Area when controlled			X	X	X	X	X	X
Perimeter at first attack				X	X			
Perimeter when corralled				X				
Perimeter when controlled			X	X	X	X	X	
Perimeter increase/hr (origin-discovery/attack)					X	X	X	

[1] Not reported.

- The 1930 Individual Fire Report, the first to include nontimber damages other than forage, established most of the categories used in subsequent years. Then, as now, nonforest damages were reported strictly in terms of dollar values.

The different approaches used since 1905 to report wildfire damages reflect the frustrations still evident today, caused by the lack of satisfactory methods for measuring impacts of wildfires on forest resources.

Table 5.—*Suppression forces and activities reported on USDA Forest Service fire reports from 1905 to 1981*

Suppression forces and activities information	1905-1909	1910-1919	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1981
Discovery/lookout tower information				X	X	X		
Travel								
Distance traveled to fire			X	X	X	X		
Method of travel			X	X		X		
Suppression forces								
Number of people at first attack			X	X	X	X	X	X
Type of first attack						X	X	X
First attack by Forest Service or other					X			
Number of people as reinforcements			X	X	X	X	X	X
Type of reinforcements						X	X	X
Total number of people	X	X	X	X	X	X	X	X
Suppression effort								
Work-hours to control			X	X		X	X	
Work-hours to mop-up			X	X		X	X	
Work-hours-total (on the line)			X	X	X			
Line built								
Total line built by hand			X	X		X		
Total line built by equipment						X		
Total chains held line					X			
Line held by equipment						X		
Total chains lost line			X	X	X			
Average chains held line or line built/work-hour				X	X			
Percent perimeter worked by equipment							X	
Suppression costs/cost class	X	X	X	X		X		X

THE 1970 INDIVIDUAL FIRE REPORT, FORM 5100-29

Content

The individual fire report (Form 5100-29) currently used by the USDA Forest Service contains 44 numbered items of information and six unnumbered items[4] used primarily for administrative purposes (fig. 4a, 4b). Not all 44 items are required for each wildfire, however; items 1-33 are reported for Class "A" fires, 1-34 for Class "B" fires, and 1-44 for Class "C" to "G" fires.

The content and design of this wildfire report are based largely on historical precedent. Well over half of the items (64 percent) have been reported continuously for 60 years or more (25 percent since 1905 and 39 percent since 1920), and nearly all of the remaining have been on Forest Service fire reports for 20 to 40 years. Only two, watershed number and value class at origin, are unique to the current form. Perhaps the greatest change in form content is in measures of fire behavior and size increase. In the past, five to seven measures were reported each decade, but now only one, total area when controlled, is on the form (table 4).

Data Use and Reliability

The individual fire report is one of the most frequently used data sources on wildfires in the country. (An average of 13,200 reports are filed each year.) According to the Forest Service Handbook, FSH 5109.14 (1970), "Form 5100-29 provides important data for planning and administering fire control activities, and for the study of techniques and problems by research and administrative personnel." Data are used not only in preparation of annual statistical summaries, but also (1) as a base for fire planning and allocation of funds; (2) to evaluate fire prevention programs; (3) to gauge fire suppression efficiency; (4) to assist in fire damage appraisal; and (5) to evaluate the National Fire-Danger Rating System (Deeming *et al.* 1977).

Because a large proportion of fire control and fire prevention planning in the Forest Service is based on fire report information, accurate and reliable data from the 5100-29's are essential. The reliability of fire report information is often questioned, however, indicating a lack of confidence in some of the report entries and resulting data summaries (Chandler 1960, Simard *et al.* 1973, Main and Haines 1974). Of the many factors affecting data reliability, perhaps the two most important are (1) the methods used to acquire and record data and (2) the attitudes of individuals completing the fire report (Simard *et al.* 1973).

The first of these two factors depends not only on the nature of the information sought, but also on the priority and immediacy given to reporting wildfire data. According to Simard *et al.* (1973):

> The information recorded [on a fire report] can vary from a precise observation to an almost random guess. Assuming a total lack of bias on the part of the reporting individual, certain information is normally quite exact. Directly observed data such as fire location and time of detection are normally highly reliable and precise data.

The authors go on to say that other observations are based on measurements that have varying degrees of precision (e.g., volume of forest products destroyed by a large fire or final area of large fires). A few factors can be naturally highly variable or imprecise (e.g., fire cause and time of ignition).

> There is another significant factor pertaining to the method of recording information which must be considered. Field personnel are concerned with fire control—not data acquisition. There are always other pressing duties which demand an individual's time and attention in addition to accurately recording information about a fire. This applies both during and after the fire. While some relatively straightforward information is normally recorded in real time, much of the more complex data may be based on memory and perhaps a few scribbled notes. Under such circumstances some loss of accuracy and detail is unavoidable (Simard *et al.* 1973).

The second factor, attitudes of individuals completing a fire report, is also important to consider when determining the quality of data reported on the 5100-29's. For example, according to Simard *et al.* (1973), in agencies where supervisors expect complete and accurate information on fire reports, individuals are likely to have good attitudes toward filling out the forms. However, if individuals filling out fire reports know that checks on their accuracy are rarely made, that their supervisors do not value proper completion of the fire reports, or that truthful reporting can lead to repercussions from superiors, they may be careless, untruthful, overly hasty, or resentful while recording information.

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[4] *Unnumbered items include fire name, ranger fire number, region fire number, remarks, and submitted and approved signatures and dates.*

Simard warns that overlooking the attitudes of individuals when they're completing the form could invalidate results based on analyses of data from these reports.

Realizing that the methods of data acquisition and recording as well as the attitudes about fire reporting may affect the quality of fire report information, we formulated a study to examine the impacts of both on data reliability. The study was also designed to obtain ideas, comments, and suggestions about various aspects of fire reporting from field personnel.

METHODS

During the 1974 and 1975 fire season, we interviewed Forest Service employees on more than three-fourths of the Ranger Districts in 12 northeastern (Region-9) National Forests. We used two interview schedules developed with the help of a survey research specialist from Michigan State University in East Lansing, Michigan. The first schedule was designed to assess respondents' confidence, measured on a scale from "Very Certain" to "Not at All Certain," in the accuracy of their fire report entries. We selected the three most recent Class A, B, and C-or-larger fire reports, if available, from District office files, and, using the forms to aid recall, interviewed the person(s) responsible for supplying the data on the three fire reports. A total of 145 reports (nearly 10 percent of the total Region-9 fire reports filed in 1974 and 1975) were examined for data accuracy. With this sample size, the confidence interval is ±8 percent of observed values at the 95 percent level. Most of these reports (88 percent) were for Class A and B wildfires. The 62 respondents to this first questionnaire included Forestry Technicians (31 percent), Other Resource Assistants (26 percent), Rangers (16 percent), District Clerks (11 percent), Foresters (10 percent), and Assistant Rangers (6 percent).

The second interview schedule was designed primarily to assess attitudes of individuals filling out the forms. In addition to collecting attitude data, however, we also tried to examine other report-related issues and problems, such as fire-report use on Ranger Districts, the priority of fire-report completion in relation to other District activities, and the time required to complete the fire reports. The 62 respondents to the second interview (not necessarily the same people as above) were Forestry Technicians (35 percent), Rangers (27 percent), Other Resource Assistants (23 percent), District Clerks (10 percent), and Assistant Rangers (5 percent). Because the Ranger Districts were chosen at random and the visited sample was large (77 percent of all Districts), the chance that attitudes and opinions at the unsampled Districts are different from those at the sampled Districts is only 0.03 at the 95 percent level.

RESULTS AND DISCUSSION OF FIELD INTERVIEWS

Respondents' confidence in the accuracy of their fire-report entries was generally quite high. Most of the individuals interviewed were very certain of their entries for equipment/personnel (92 percent),[5] fuel/site description (86 percent), and fire times (86 percent if item 14 is excluded) (fig. 5). The number of respondents expressing high certainty in remaining entries, however, gradually decreased: acreage/timber destroyed (75 percent), fire danger/weather (65 percent), value of resources damaged or destroyed (61 percent), and fire causes (59 percent). Overall, though, more than half of the respondents said they were very certain of their entries for items 10-44 except for Item 14, time of fire origin. Using a confidence interval of ±8 percent of the average percentage for each group, we found that groups A, B, and C (excluding Item 14) are significantly different from groups E, F, and G (fig. 5). Therefore, if we assume that degree of certainty indicates degree of data reliability, those using data from fire reports can place more confidence in entries describing equipment, personnel, fire times, fuels, and site factors than in the rest of the entries.

In conjunction with "certainty" data, we also recorded respondents' years of fire reporting experience, source of information for each of the items 10-44, and times involved in completing each fire report, thinking that these factors may affect data reliability. We found that:

- Years of fire reporting experience ranged from less than 1 year to 30 years, with a median of 7 years.
- In addition to collecting and supplying their own data, respondents used other information sources for their fire report entries. For example, in addition to maps and weather records, they gathered data from dispatchers, aircraft patrol pilots, fire wardens, local fire departments, and seasonal or permanent local residents. Nearly 86 percent of the fire report data, however, were supplied by Forest Service technicians and foresters.

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[5] *The percent in parentheses is the average percent of respondents in that group.*

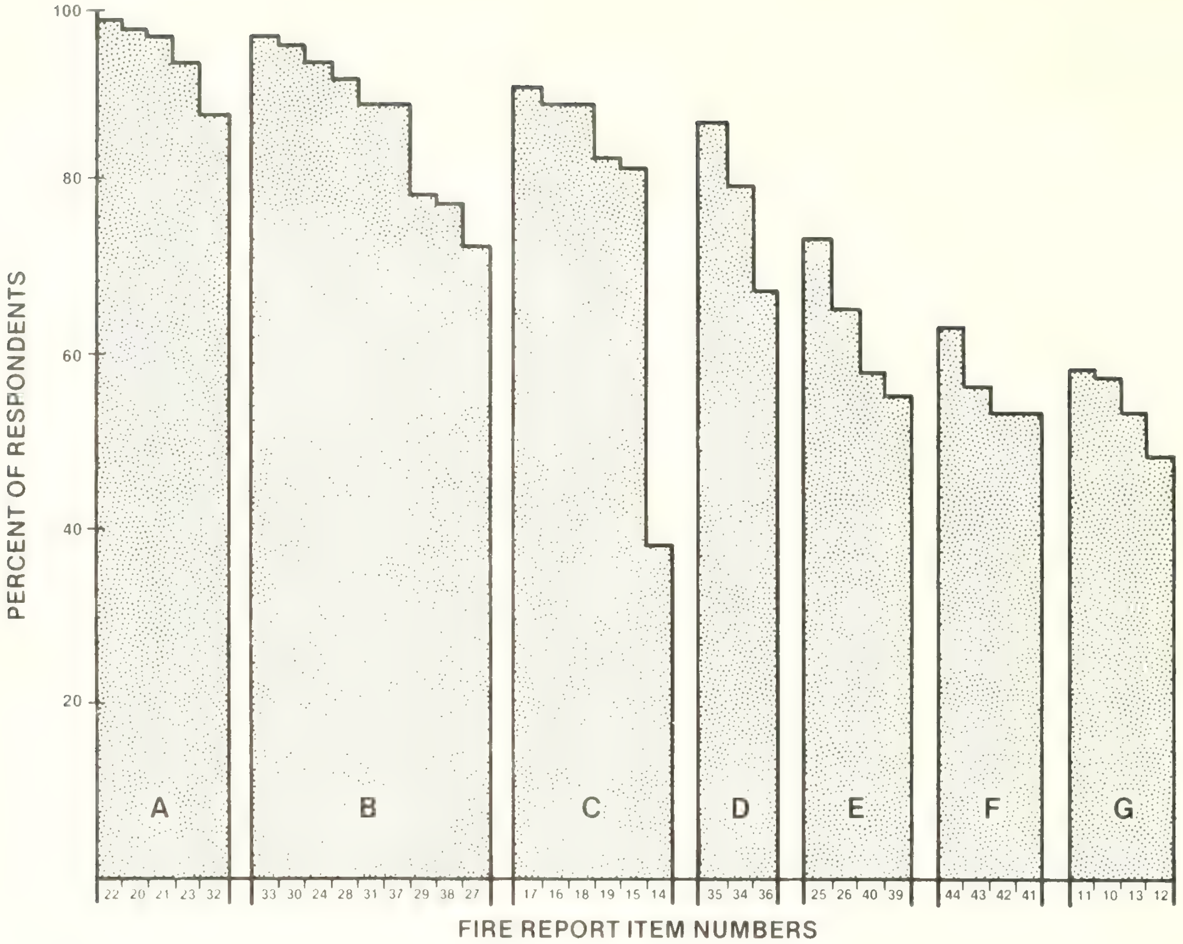

Figure 5.—*Percent of respondents who were very certain of the accuracy of their fire report entries for items 10-44. Fire report items and numbers corresponding to those on the current (1970) Forest Service Individual Fire Report, Form 5100-29, are grouped into seven subject areas.*

A—Equipment and personnel; B—Fuel and site description; C—Fire times; D—Acreage and timber destroyed; E—Fire danger and weather; F—Value of resources damaged or destroyed; and G—Fire causes.

- Regardless of fire size class, more than half of the fire reports were ready for an approving officer's signature in a day or two and more than three-fourths were ready within a week after the fire, indicating that reports were generally given prompt attention when the data were still relatively "fresh" in people's minds. The amount of time actually spent on a fire report, including time spent investigating the fire cause, collecting information, and filling out the form, varied widely. Investigation times ranged from 0 minutes to approximately 20 hours (median = 40 minutes), collecting data and filling out the form required from 5 minutes to 8 hours (median = 2 hours), and the total time to do all three activities ranged from 30 minutes to 26 hours (median = 3 hours). As expected, Class A and B fire reports generally required less time to complete than C and D reports; four out of five A/B 5100-29's were finished in 4 hours or less, but only one-third of C/D reports were completed in the same time period. None of the variables—years of reporting experience, source of fire information, or form preparation times—showed significant correlations with respondents' certainty in fire report entries.

As an independent check on data accuracy, we examined each of the 145 fire reports for coding errors. Nearly half of them (47 percent) had one or more errors due primarily to miscoding written information. This error rate is compatible with historical analyses conducted in the 1940's and 1950's.[1] For example, a Region-3 work simplification study conducted in 1944 showed that 54 percent of the Class A and B fire reports had similar coding or entry mistakes. Although errors occurred in 17 different fire report items on the current (1970) 5100-29, most of them were concentrated in Items 14-18 (fire times) and in Items 30 and 31 (cover and fuel types). Errors were not only made in information generally considered highly reliable, but they were also undetected, indicating that better fire report instructions are needed, coding procedures should be simplified, and more time must be devoted to data verification.

People with fire reporting responsibilities generally have attitudes and opinions about the 5100-29 that may affect how the report is processed and used or what priority it has in relation to other activities. They are also in an excellent position to identify problems with the reporting system and recommend useful changes from a field perspective. Our findings show that:

- More than half of the respondents had a positive attitude toward the 5100-29, primarily because of the valuable data the form supplies. Nearly three-fourths said it had a useful purpose—to supply information that would aid managers at various administrative levels and also facilitate research, fire planning, fire prevention, and historical data analysis. The positive attitude was also attributed to the form itself; it was simpler to complete and better than the form it replaced.

- Those who reported negative attitudes toward the 5100-29 (one-fourth of the respondents) were dissatisfied with it for the following reasons, listed in descending order of importance: (1) it requires a great deal of time and effort to fill out; (2) it contains ambiguous and useless items; (3) the format and coding are too complicated and confusing; (4) the form design and arrangement impair readability; and (5) some fire report entries are inaccurate because it's difficult to reduce complex events to simple codes. Negative reactions to the fire report also stemmed from pressure to submit the form on time and from the emphasis it received relative to its perceived importance.

- Four-fifths of the respondents used some of the information (although it was often rather minimal) from the 5100-29 on the job. Data were used primarily to determine fire occurrence patterns and as an aid to fire planning and prevention. They were used less frequently as input into law enforcement analyses and court cases and in fire-danger assessment.

- Completion of the 5100-29 had high priority on most Ranger Districts; only 7 percent of those interviewed said it received low priority and another 23 percent assigned it medium priority. Even though the form generally received immediate attention after a wildfire, nearly three-fourths of the respondents reported delays in preparing it during peak fire periods. Although one District reported delays as long as 35 days, most submitted the forms within a week after the fire.

- District personnel were asked to indicate the degree of difficulty (ranging from not at all difficult to very difficult) encountered in understanding the fire report instructions, obtaining data for each item, properly entering data on the form, and finding time to complete the 5100-29. In all cases, close to half of the respondents said these tasks were not too difficult, although finding time and obtaining data for each item were judged reasonably difficult by more than a fourth of those interviewed. Overall, understanding the instructions was the least difficult and finding time to complete the form was the most difficult.

- The question received most enthusiastically by District personnel was how they would improve the 5100-29. Of the 87 percent who said it needed improvement, most offered suggestions for changes in form content and design (see the Appendix).

- Along this same line, we asked if other fires should be included on the fire report. About 25 percent said they would like to see nonstatistical fires, prescribed fires, and managed wildfires, singly or in combination, reported on the 5100-29.

- Only 25 percent of the respondents surveyed the form in depth for completeness and accuracy before the final signature. Forty percent partially examined the form, and one-third gave the form only a cursory review. This may account, in part, for the undetected coding errors discussed earlier.

Some relations between variables that we examined were not significant. In addition to those already mentioned, we found that respondents' attitudes about fire reporting were unrelated to their years of fire reporting experience, to their use of fire-report information on the job, and to the priority the 5100-29's received in relation to other District activities. Our analysis also indicated that use of fire-report information had no correlation with the perceived purpose of the form or its priority on the Ranger Districts. Low correlations between these variables may be due in some cases to poorly formulated questions, but on the whole, we can find no evidence that relations between these variables exist.

SUMMARY AND CONCLUSIONS

The USDA Forest Service Individual Fire Report, Form 5100-29, reflects a long tradition of fire reporting begun in 1905; both its content and design are based largely on historical precedent. Because the report provides valuable wildfire data used for various purposes by operational, administrative, and research personnel, the reliability of the information on the form is a continuing concern. We found that fire report information is generally reliable and that, as Simard *et al.* (1973) suggested, directly observed data are more reliable than hard-to-observe data such as value of resources damaged or destroyed or wildfire causes. Even though not all fire report data are recorded in real time, our study indicates that data reliability does not decrease significantly as the time between fire occurrence and report form completion increases. It would seem, as Simard *et al.* (1973) contend, that some loss of accuracy and detail is unavoidable, but apparently it's not serious enough to cause field personnel to lower their confidence in their fire report entries. These results, however, may be due to a bias in our sample, in that the time from fire occurrence to form completion was generally short (1 to 7 days).

The median time required to complete a fire report (3 hours) may have a large impact on the total workload of Ranger Districts that have many fires. We believe that a sudden increase in workload can influence the quality of data entered on the fire report. Attention to detail and accuracy might be sacrificed as efforts to save time and process the reports quickly take precedence. Less effort may be given to fire-cause investigation, thorough documentation, and careful measurement of other fire-related parameters. As a result, best "guesstimates" may be entered on the report.

Given the high number of coding errors, fire report validation is still a problem, indicating a need for quality control at higher administrative levels. Fire report items most frequently miscoded, especially fire times and cover and fuel types, should be examined more closely for errors.

The positive attitudes toward fire reporting expressed by so many of the District personnel are encouraging, and the high percentage of people finding the fire reports useful indicates that they're seeing tangible results from their reporting efforts. Perhaps these positive attitudes and support for fire reporting have an effect on the reliability of the information entered on the fire report. On the other hand, people with negative responses to the 5100-29 had concrete reasons for their attitudes which managers can directly address if they wish to bring about attitude changes in this particular group. Changes could be made in form design or in management directives and requirements, for instance, that would reduce the time and effort needed to fill out the form, make the reporting system simpler to use, or clarify the need for certain types of information routinely reported.

Only 7 percent of the Ranger Districts considered the 5100-29 a low priority item, indicating that the Regional Office mandate, requiring that each report be sent in within 10 days of the fire, was effective. On the negative side, this mandate may also have been partially responsible for the many coding errors made in haste in order to submit the form to the Regional Office on time. The revised regional fire report instructions now provide a little more flexibility; the original copy of the 5100-29 is due not later than the 10th of the month following the month the fire occurred.

Finally, District personnel, ultimately responsible for the data entered on the 5100-29, have excellent ideas and suggestions about fire reporting that should not be ignored by those redesigning the system, making simple changes, or in some other way altering the form and its contents. Their day-to-day experiences and frustrations with the form are worth noting and can serve to improve both the quality of data obtained from the fire reports and the ease and efficiency with which data are entered on the form.

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APPENDIX

Examples of Fire Report Form Content and Design Changes Recommended by District Personnel

Content changes

1. Reduce the number of items reported for Class A and B fires.
2. Consolidate Items 10-12 (fire causes) and re-design them to reflect actual field situations.
3. Re-design cover and fuel types to facilitate easier, accurate reporting.
4. Emphasize or require written remarks to supplement coded data.
5. Include degrees of certainty with difficult-to-measure parameters such as fire cause.
6. Incorporate the law enforcement report to reduce repetitious reporting.
7. Change Item 21 (First Attack by) so that a combination of first attack forces can be reported.
8. Clarify the definition of "Amount" entries required for Items 21-22 (First Attack by and First Reinforcements).
9. Incorporate additional weather features contributing to fire danger.
10. Clarify differences between statistical and nonstatistical fires.
11. Eliminate repetitious items such as 26 & 40 (weather feature); 30, 31, & 37 (cover and fuel types); and 34 & 36 (acreage).
12. Include an item recording wildfire benefits.
13. Adjust Item 38 (Topography—vicinity of origin) categories to reflect Region-9 topography.
14. Use one report for string sets, but include an item giving the total number of incendiary or railroad fire sets.
15. Eliminate latitude, longitude, and watershed number.
16. Include provisions for changing or correcting entries after the report has been submitted.
17. Incorporate fire behavior items.
18. Eliminate items that are not used in fire management planning or in statistical reports.

Design changes

1. Consolidate most important information, such as date and cause of fire and acreage burned, in one area on the form.
2. Divide the form into two sections—one for write-in entries; one for coded entries.
3. In FSH 5109.14, Individual Fire Report Handbook, compile one set of fire report instructions that sequentially incorporates regional supplements and fire report information from other Forest Service manuals.
4. Re-design the form for easy typing. It should be one-sided with proper spacing, item sequencing, and directions that eliminate the use of a template.
5. List acreage categories corresponding to each size class.
6. Use color-coded snap sheets indicating form distribution.
7. Increase space available for narratives.
8. Change map size to 4 inches to the mile.
9. Eliminate write-in data; record only numerical codes or check one of several alternatives for each item.

Donoghue, Linda R.

The history and reliability of the USDA Forest Service wildfire reports. Pap. NC-226. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 15 p.

Traces the history of USDA Forest Service fire reports, examines the most recent report, Form 5100-29, and discusses the reliability of information recorded on the 5100-29, factors influencing data accuracy, and reactions of Ranger District personnel to wildfire reporting.

KEY WORDS: Form design, fire reports, wildfire reporting.

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Research Paper **NC-227**

Rates of Forest Floor Decomposition and Nutrient Turnover in Aspen, Pine, and Spruce Stands on Two Different Soils

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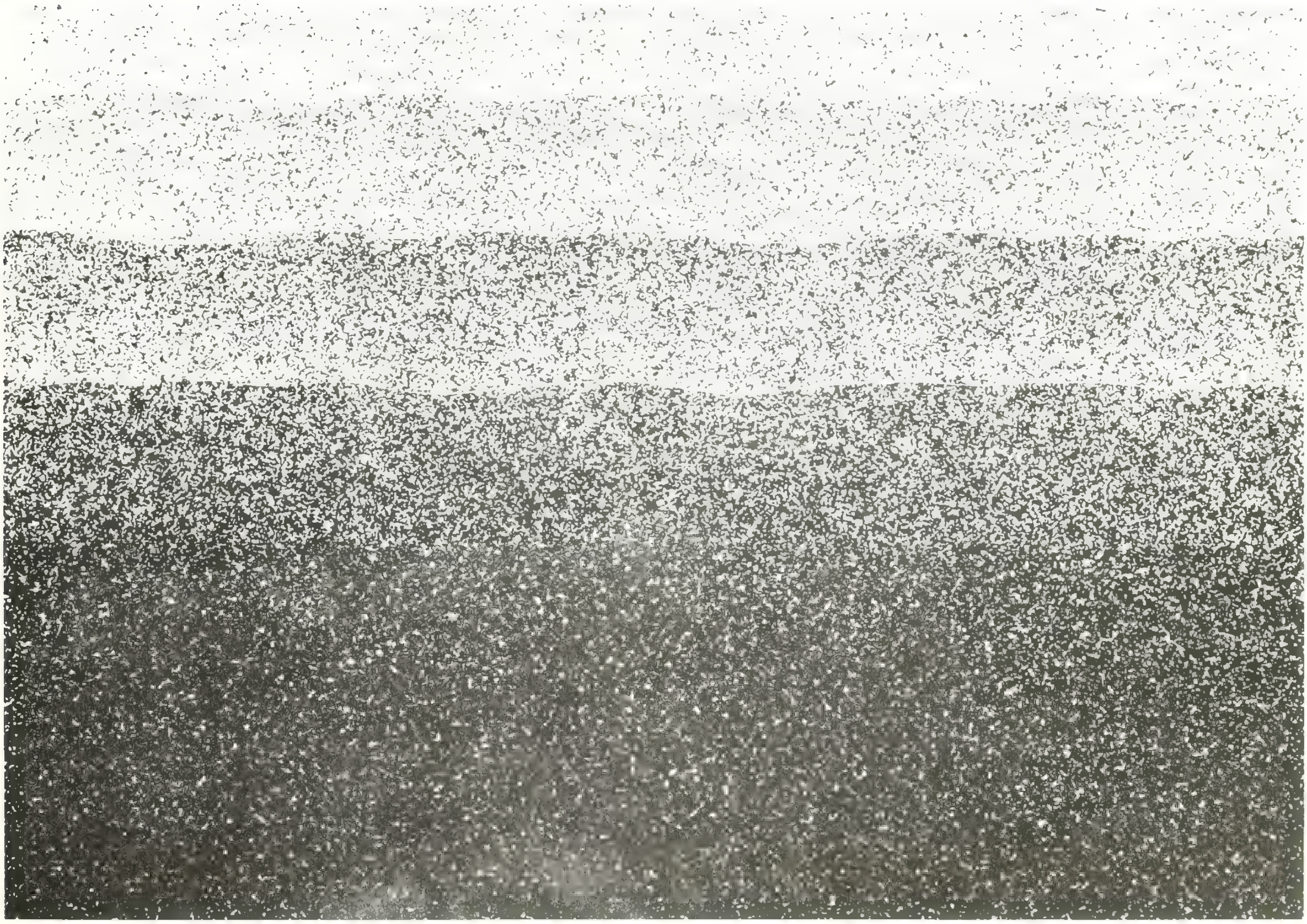

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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1982

RATES OF FOREST FLOOR DECOMPOSITION AND NUTRIENT TURNOVER IN ASPEN, PINE, AND SPRUCE STANDS ON TWO SOILS

D. A. Perala, *Principal Silviculturist,*
and **D. H. Alban,** *Research Soil Scientist*
Grand Rapids, Minnesota

Tree nutrition—that is, nutrient uptake, retention, and return in litterfall—is fundamentally distinct from the nutrition of annual agronomic crops. The conservation of nutrients in forests by intracycling provides an important portion of annual nutrient demand. In part, it allows good forest growth on soils that would be poor or unsuitable for agriculture.

But before nutrients returned in litterfall can again be available to trees, they must be mineralized. Nutrients, especially large amounts of K, are made available to some degree through direct leaching. The remaining nutrients are mineralized largely by biological activity—soil micro-organisms, soil animals, and saprophytic plants utilize the organic matter directly as an energy source in their metabolism. Mineral nutrients are eventually released in plant available forms upon the death of the micro-organisms and their predators, or in their waste products. Nitrogen in organic matter is transformed by many biological processes and some becomes available to plants during the nitrogen cycle (Swift *et al.* 1979).

Since the metabolic rate of soil organisms depends on temperature, moisture, pH, and aeration, rates of forest floor decomposition and nutrient turnover vary with environment. The nature and quality of the litter (ease of breakdown) are also important; these vary among tree species, and particularly between conifers and hardwoods (Swift *et al.* 1979).

While many researchers have reported decomposition and nutrient turnover rates for individual forest stands (Olson 1963, Cole and Johnson 1978, Krause *et al.* 1978, Lousier and Parkinson 1976), comparisons among species on the same soil type are rare. Yount (1975) compared white pine and hardwoods on the Coweeta Watershed, but species comparisons replicated on more than one soil are, to our knowledge, nonexistent. In this paper, we will present estimates of forest floor organic matter decomposition and nutrient turnover rates for trembling aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* (Moench.) Voss), red pine (*Pinus resinosa* Ait.), and jack pine (*P. banksiana* Lamb.) growing on two soils of somewhat different site quality.

STUDY AREA

The study area is located on the Chippewa National Forest in north central Minnesota, U.S.A. (47° 20′ N, 94° 30′ W), in the spruce-fir forest ecoregion (Bailey 1980). The climate is humid warm-summer continental, with cold winters. Annual temperature and precipitation average 4°C and 610 mm.

Both soils occur on a gently undulating till plain. One soil is a Warba very fine sandy loam (Glossic Eutroboralf), well drained, with pH of 5-6 above the calcareous C horizon. The other soil is an unnamed loamy fine sand (Arenic Eutroboralf) underlain at 80 cm by calcareous loam, well drained, with pH of 5-6 in the solum.

About 8 ha were cleared on each soil in either 1933 (loam) or in 1934 (sand), and 0.4 ha adjoining plantations were planted in the autumn of 1933 and 1934 with red pine, jack pine, or white spruce. An unplanted control area on the loam developed through suckering into a fully stocked, even-aged aspen stand. No such control area was established on the sand, but an adjacent two-aged (years of origin 1918 and 1926) aspen stand was available for study instead.

Forty-four species in the shrub and herb layers were present on both soils, most commonly *Corylus cornuta* Marsh., *Lonicera canadensis* Marsh., *Aster*

Table 1.— *Stand overstory characteristics*

Stand	Soil^{1}	Age	Trees/ ha	Mean height	Mean d.b.h. o.b.	Basal area	Biomass	50 year site index
		Yrs.	*Number*	*m*	*cm*	*m²/ha*	*t/ha*	*m*
Aspen	L	40	2,989^{2}	20.3^{3}	18^{3}	41.7^{2}	205^{2}	21.9^{3}
	S	49	1,237^{2}	19.8^{3}	24^{3}	36.8^{2}	211^{2}	21.4^{3}
Spruce	L	39	2,187	14.4	15	41.1	185	19.7
	S	41	2,718	13.7	14	44.9	179	18.6
Red pine	L	39	1,780	17.6	19	51.9	243	20.7
	S	41	2,364	16.9	16	49.2	200	19.6
Jack pine	L	39	1,580	18.4	17	35.1	175	21.7
	S	41	1,236	19.3	18	30.4	150	21.6

[1] L = loam, S = sand.
[2] Includes middle-story hardwoods.
[3] Aspen only.

macrophyllus L., *Maianthemum canadense* Desf., and *Thalictrum dioicum* L. Sixteen species were found exclusively on the sand, including *Vaccinium myrtilloides* Michx., *Rubus strigosus* Michx. and *Streptopus roseus* Michx., and 15 were exclusive to the loam, most notably *Acer saccharum* Marsh., *Tilia americana* L., and *Actaea rubra* (Ait.) Wild. The stand tree characteristics at the time of sampling are given in table 1. More detailed descriptions of the soils and study areas can be found in Alban *et al.* (1978) and Perala and Alban (1982).

METHODS

In early September 1972 (loam soil) and 1974 (sand), ten 4-m² circular understory sampling plots were systematically located in each stand. All herbaceous vegetation was clipped at the ground line to determine biomass and nutrient content (Alban *et al.* 1978). Herbaceous vegetation was inventoried in this manner because it could not be accounted for in litterfall from the tree and shrub layers.

From August 1, 1974, to August 1, 1976, four 1-m² litter traps were systematically located (in stands of each species) on each soil. Litter collections were made five or seven times a year, concentrating in the autumn during maximum litterfall. For purposes of analysis, samples were composited into two sample periods: August to November, and November to August; but only annual averages are reported here.

Forest floor samples were collected with 930 cm² metal frames from 40 locations per stand in October 1972 (loam) and July 1974 (sand). To ease the analytical load, forest floor samples were composited in the field to give 10 samples (loam) and 8 samples (sand).

Samples of litter, herbs, and forest floor were ground to pass a 20-mesh screen and were all analyzed in the same manner. Carbon was determined by induction furnace (Allison *et al.* 1965) and N by the macro-Kjeldahl method (Bremner 1965). After dry ashing (500°C), Ca, Mg, and K were determined by atomic absorption, and P by the molybdophosphoric blue colorimetric method (Jackson 1958). Organic matter in herbs and litterfall is simply the ovendry (70°) weight uncorrected for ash; forest floor is corrected for ash.

For the sand, August to November litterfall averages for organic matter, C, and nutrients were added to the forest floor to adjust for differences in forest floor sampling times. Thus the forest floor values represent the period immediately following leaf drop for native deciduous trees. The steady-state exponential decay model of Olson (1963),

$$k = \frac{\mathrm{L}}{\mathrm{Xss}}, \tag{1}$$

was used to estimate instantaneous fractional loss rates (*k*) for organic matter, C, and nutrients in forest floor. In this equation, L = annual litterfall weights and Xss = forest floor weights in the steady-state. Half-lives of organic matter, C, and nutrients in the forest floor were estimated from the *k* values using the equation

$$t = \frac{\ln(0.5)}{-k} = \frac{-0.693}{-k}, \tag{2}$$

rewritten from Olson (1963),

$$\ln(\mathrm{X}/\mathrm{X}_o) = -kt \tag{3}$$

where t = time (years), and X_o = original amount of litter organic matter, C, or nutrients, and X = amount remaining.

RESULTS

Depending on species, annual litterfall weights averaged from 6 to 18 percent less on the sand soil than on the loam (table 2). The stands on both soils had less litterfall the second year (herbs not considered since they were sampled in only 1 year), ranging from 7 percent less for aspen to 31 percent less for jack pine. During the 2 years, the ranking by species in total litterfall and in C was red pine > jack pine > spruce > aspen for both soils. All nutrients in spruce and red pine litterfall were less on the sand than on the loam, but this varied in aspen and jack pine. In spite of having the least litterfall weight, aspen had the greatest amount of litterfall P, K, Mg, and, along with spruce, Ca. Spruce and jack pine litterfall had the most N. Carbon was least on the sand for all species.

Overall, organic matter (OM) and C in the forest floor were less on the sand than on the loam (table 3). Aspen had the least forest floor OM and C on both soils, while the conifers were nearly identical. The forest floor on the sand had only 45 to 72 percent of the nutrients found in the forest floor on the loam. The forest floor nutrient levels varied widely among species.

The half-lives of OM, C, and nutrients were shorter on the sand than the loam except for red pine OM and C (table 4). The order of half lives for OM, C, and nutrients in the aspen forest floor was N>Ca>Mg>P>C>OM>K, whereas in the conifers it was generally Ca>N>Mg>P>C>OM>K. Thus, all nutrients, except K, were enriched in the forest floor. The ranking of half-lives among species varied depending on nutrient. Spruce had the longest half-lives for K, Mg, and, along with jack pine, P and Ca. Aspen had the shortest half-lives for P, K, Ca, and, along with red pine, Mg. Aspen also had the longest half-lives for OM, and, along with spruce, C and N. Generally, half-lives for jack pine were longer than for red pine.

Table 2.—*Organic matter, C, and nutrients in annual litterfall*[1]
(In kg/ha)

Stand	Soil[2]	Organic matter	C	N	P	K	Ca	Mg
Aspen	L	4,382	1,972	40	8.2	24	81	8.7
	S	4,105	1,888	39	8.3	34	64	9.2
Spruce	L	5,727	2,520	54	6.9	16	83	4.8
	S	5,263	2,421	41	5.1	12	60	4.1
Red pine	L	6,916	3,389	46	4.9	19	40	7.0
	S	5,638	2,875	37	3.7	18	26	5.8
Jack pine	L	6,210	2,919	51	4.6	17	45	6.5
	S	5,607	2,467	46	4.8	20	31	5.8

[1] Mean of two collection years, plus herbs.
[2] L = loam, S = sand.

Table 3.—*Organic matter, C, and nutrients in forest floor*
(In kg/ha)

Stand	Soil[2]	Organic matter	C	N	P	K	Ca	Mg
Aspen	L	26,840	13,530	667	60	78	1,081	89
	S	22,890	11,580	467	38	51	586	64
Spruce	L	33,080	17,580	752	61	76	1,398	77
	S	28,070	14,050	517	42	49	781	48
Red pine	L	30,290	15,800	538	40	62	660	65
	S	29,390	14,890	370	26	39	294	43
Jack pine	L	32,750	16,860	689	51	68	770	81
	S	27,560	13,480	486	34	44	391	53

[1] L = loam, S = sand.

DISCUSSION

The half-life estimates given here are suitable for comparing gross differences between species-stands and soils (Swift *et al.* 1979), but their absolute values are less reliable for a number of reasons. First, the annual variation in litterfall is tremendous. For example, over a 7-year period, Ebermayer (1876, cited by Alway and Zon 1930) observed nearly a threefold range in pine litterfall in Bavaria. Second, there can be large yearly and seasonal variation in forest floor weight and nutrients (Yount 1975). Third, nutrients are added to the forest floor from precipitation, through-fall, stemflow, and N-fixation. Fourth, nutrients are retained on exchange sites or by microbial immobilization, and fifth, nutrients are transfered by roots or hyphae. Clearly, the cycling process is enormously complex (Lousier and Parkinson 1976, Swift *et al.* 1979, Yount 1975).

Table 4.—*Half-lives of organic matter, C, and nutrients in forest floor*
(In years)

Stand	Soil[2]	Organic matter	C	N	P	K	Ca	Mg
Aspen	L	4.2	4.8	11.6	5.1	2.3	9.3	7.1
	S	3.9	4.3	8.3	3.2	1.0	6.3	4.8
Spruce	L	4.0	4.8	9.7	6.1	3.3	11.7	11.1
	S	3.7	4.0	8.7	5.7	2.8	9.0	8.1
Red pine	L	3.0	3.2	8.1	5.7	2.3	11.4	6.4
	S	3.6	3.6	6.9	4.9	1.5	7.8	5.1
Jack pine	L	3.7	4.0	9.4	7.7	2.8	11.9	8.6
	S	3.4	3.8	7.3	4.9	1.5	8.7	6.3

[1] L = loam, S = sand.

Finally, the assumption of steady-state cannot be entirely substantiated, although there is strong supporting evidence. The forest floor weights reported here for red pine differ little from those of Minnesota stands 44 to 94 years old (Alban 1974) or 100 and 250 years old (Alway and Zon 1930). There are similar comparisons for jack pine up to 55 years old (Alway and Zon 1930). Therefore, the steady-state assumption does not seem to introduce serious error.

In spite of these many uncertainties, the results compare favorably with those of similar studies. Carbon in the forest floor and annual litterfall in these stands was comparable to those in forests of the eastern United States (Olson 1963). The overall range of *k* (.14-.22) is medium-high according to Olson (1963), and again within the range reported for eastern conifers. In this study, the range of litter and forest floor C values among species and soils is as great as the range among other stands growing across the eastern U.S. The half-lives for OM are as expected; they are longer than for tropical forests and somewhat longer than for other temperate forests, but much shorter than for boreal forests (table 5). Half-life for aspen litter was slightly longer than for aspen leaf litter after 30 months in 3-mm-mesh bags in Alberta, Canada (Lousier and Parkinson 1976).

The half-lives of nutrients in the forest floor (table 4) were considerably longer than those in other temperate and especially tropical forests, but not much different from those in boreal forests (table 5). The exception was the half-life of N, which is generally much longer in boreal forests.

Nutrient turnover (except for K) lagged behind the turnover of organic matter, a universal observation (Swift *et al.* 1979). The many reasons for this were mentioned earlier.

Forest floor nutrients on the relatively nutrient-poor sand soil were recycled more rapidly than on the loam. This compensated somewhat for the lower inherent fertility of the sand and forest productivity was comparable to the more fertile loam soil (table 1). Why turnover rates were higher on the sand is not known. Tappeiner and Alm (1975) found rapid forest floor decomposition when understory plants were present, especially in red pine stands. The greater proportion of nutrient-rich and relatively easily decomposed litter contributed by shrubs and herbs on the sand (Perala and Alban 1982) accounts in part for faster mineralization. However, litter from the tree layer is not known to decompose faster when mixed with understory litter.

Table 5.—*Literature values for half lives of organic matter and nutrients in forest floor*
(In years)

Location or species	Organic matter	N	P	K	Ca	Mg	Reference
TROPICAL FOREST							
Costa Rica	0.29	—	—	—	—	—	Table 7, Cole and Johnson (1978)
Ghana	.15	0.15	0.21	0.10	0.15	—	
West Indies	.42	.55	.63	.17	.19	—	
Columbia	.41	.59	—	—	—	—	
Florida	.53	1.56	—	—	—	—	
BOREAL FOREST							
Jack pine	5.1	7.5	10.0	1.5	2.6	3.7	Table 6, Krause *et al.* (1978)
Black spruce	18.9	43.0	—	—	—	—	
Balsam fir	9.7	17.3	18.7	7.5	4.0	—	
Aspen	12.3	32.6	8.3	4.9	9.7	8.3	
TEMPERATE FOREST							
White pine	2.5	.86	5.4	.20	3.2	1.2	Yount (1975)
Hardwoods	.82	.32	.92	.23	1.2	.61	
Red pine	8.4	21.3	14.8	8.6	12.2	—	Alway & Zon (1930)
Jack pine (age 30)	3.5	7.7	7.3	6.4	5.7	—	
Jack pine (age 55)	7.7	13.0	11.3	10.0	9.7	—	
Red pine-hazel	2.2	3.3	2.9	2.1	1.7	1.2	Tappeiner & Alm (1975)
Paper birch-hazel	1.2	2.3	0.8	0.1	1.0	0.5	

CONCLUSIONS

This study showed strong indirect effects by tree species and soils on the rate of nutrient turnover in the forest floor. Comparisons with results from other studies indicate that turnover rates of nutrients and organic matter vary widely within the same ecoregion, and even within species. Detailed studies of decomposer organisms and their microenvironment are needed to explain these differences.

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Rates of forest floor decomposition and nutrient turnover in aspen, pine, and spruce stands on two soils. Res. Pap. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 5 p.

Compares rates of forest floor decomposition and nutrient turnover in aspen and conifers. These rates were generally most rapid under aspen, slowest under spruce, and more rapid on a loamy fine sand than on a very fine sandy loam. Compares results with literature values.

KEY WORDS: Mineralization, nutrient cycling, litterfall, nitrogen, phosphorus, potassium, calcium, magnesium.

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Drying Small Quantities of Green Hardwoods

Charles M. Miceli, Howard N. Rosen, and Howard A. Spalt

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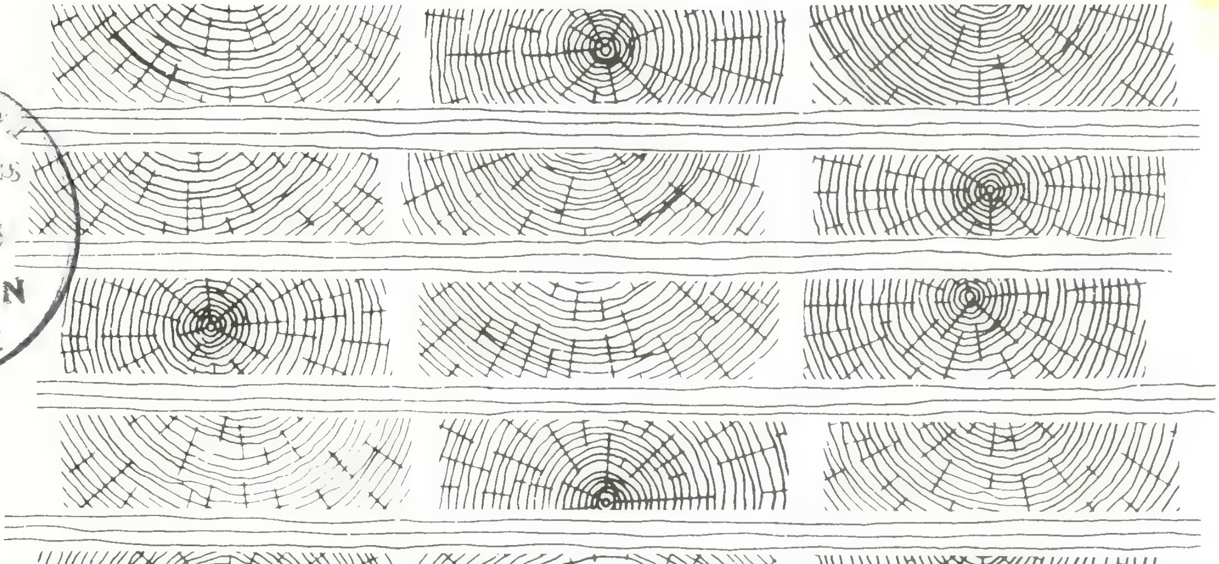

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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DRYING SMALL QUANTITIES OF GREEN HARDWOODS AT HOME

Charles M. Miceli, *Research Assistant,*
Department of Forestry,
Southern Illinois University at Carbondale,
Howard N. Rosen, *Research Chemical Engineer,*
North Central Forest Experiment Station,
Carbondale, Illinois,
and **Howard A. Spalt,** *Associate Professor,*
Department of Forestry,
Southern Illinois University at Carbondale

Woodworking hobbyists desiring to dry green lumber or freshly cut cross sections of tree stems may find little information to guide them in their undertaking. Hobbyists can readily obtain practical information on the machining and finishing of wood, but little comparable information is available about drying green wood to the low moisture contents required for most woodworking projects.

In our search of publications available to the hobbyist we found only a few items dealing with drying green wood. For example, Rasmussen (1965) provides some useful general directions that the experienced woodworker may apply. Bois and Wengert (1977) prepared a checklist for hobbyists planning to cut logs into lumber and dry the boards produced. Neither of these items advises the woodworker about the effects of species, thicknesses, and drying conditions on the length of time to dry all quantities of short lumber (less than 8 feet long) to the desired moisture content or the amount of defects that will develop during drying.

This study was undertaken to evaluate methods that the hobbyist might use to dry green lumber. We wanted to find a low-cost method that required little or no equipment and could be carried out in locations common to most yards and houses. The evaluation was based on actual drying trials under conditions likely to be encountered by the hobbyist so the results obtained in this study should be comparable to the results a hobbyist would obtain practicing the same methods.

METHODS

We determined the effect of species, thickness, and drying location on the time to dry green boards and cross-sectional disks to the 6 to 10 percent moisture contents required for many woodworking projects. Species considered difficult to dry, moderately difficult to dry, and easy to dry were represented in that order by white oak (*Quercus alba* L.), black cherry (*Prunus serotina* Ehrh.), and silver maple (*Acer saccharinum* L.). Five-foot-long bolts were obtained locally from trees 12 to 18 inches d.b.h. Full-section disks, 1 inch and 2 inches thick along the grain, were cut from the ends of the bolts so that the drying characteristics of full cross sections could be studied also. The bolts were cut on a portable bolter saw to boards 4/4 and 8/4 thick and edged on a table saw to 6 inches wide. One hundred twenty boards for each species were produced; 60 boards were cut to 4/4 thickness and 60 to 8/4 thickness.

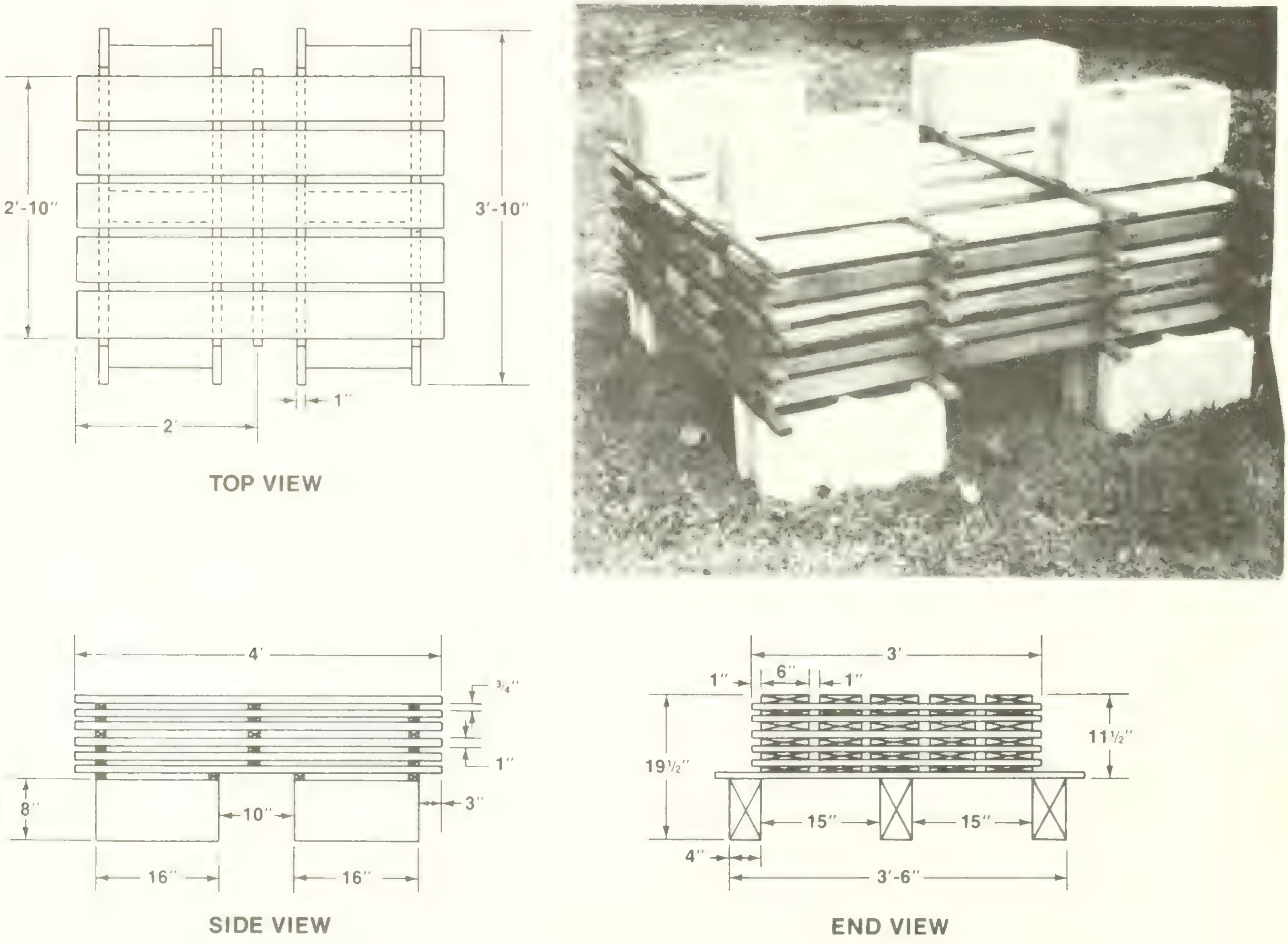
After sawing, 6 inch-long pieces along the grain were trimmed from each end of every board and half-inch-long moisture content specimens were cut from the inner portion of this end trim. These moisture specimens were wrapped in plastic immediately after cutting, weighed, and ovendried to determined moisture content of each board. The boards were segregated by species and thickness into 24 bundles of 5 boards each. These were wrapped immediately in plastic and stored in coolers and 35° F until needed.

The following six locations were selected for the drying tests: heated room with fan, heated room, unheated shed, outdoors under roof, unheated attic with fan, and walk-in freezer.

Attics, sheds, and outdoor spaces were selected because they are often underutilized and would be readily available. Heated indoor space was included because the low moisture content targets and slow drying outdoors in winter would necessitate heated locations, at least for final drying.

Two stacks of 30 boards each were constructed at each site (fig. 1). In building the 12 stacks, boards of each species and thickness were removed from the plastic wrap, weighed to the nearest 0.01 pound, measured for width and thickness at four different points along their length, end coated with paraffin to reduce end checks, and stacked between 3/4-inch stickers to promote air flow across the surface of the boards. The stacks are arranged in alternate rows of 4/4 and 8/4 lumber with the species arranged randomly in each row. Cement blocks were placed on top of the pile to help keep the boards flat (fig. 1). In the heated room and the unheated attic a 20-inch-diameter fan was placed 3 feet from the face of the stack.

When wood is worked indoors, the lumber should be dried to less than 10 percent moisture content. The relative humidity of outside air is often too high to dry wood quickly much below 20 percent moisture content; consequently, the material in the shed, under the roof, and in the attic were dried outdoors to 20 percent moisture and then moved into a heated room and restacked. Drying continued indoors until the weights of selected sample boards indicated a moisture content below 10 percent.



TOP VIEW

SIDE VIEW

END VIEW

Figure 1.—*Typical lumber stack and arrangment when drying lumber.*

Disks were dried in a heated room with a fan and in the freezer. In the heated room, the disks were placed on stickers that spanned the space between the cement blocks on top of the stack. In the freezer, the disks were placed on stickers that had been arranged on shelves that lined the freezer wall. Prior to drying, the disks were weighed to the nearest 0.01 pound and their moisture contents measured with a penetrating, resistance-type moisture meter that gave the data required to calculate the ovendry weights of the disks.

At each drying location, temperature and humidity conditions of the ambient air were measured and repeat measurements were made once a week until the end of the drying period. At each site, weights of six selected boards (one board for each species and thickness) were monitored weekly for moisture content. At the end of the drying period, weights, dimensions, and warp (crook, bow, cup, and twist) were measured. Also three 1-inch-long stress sections and three moisture sections were cut from the ends and center of each of the sample boards for estimating case hardening and determining differences in shell and core moisture contents by standard tests (Rasmussen 1961).

The cross-sectional disks of each species were divided into two groups of six disks each, one disk of each species and thickness. We kept one group in a heated room for 8 months, and the second group first in a freezer for 13 months and then in a heated room for final drying. We weighed the disks periodically so we could calculate their moisture contents as drying progressed. At the end of the drying period, we measured the number, length, and maximum width of splits that developed.

The experiments were designed for statistical analysis using the analysis of variance technique for testing the effects of the three main variables—species, thickness, and location—and their interactions on the drying times and drying defects. The responses tested were total number of days to dry to 10 percent moisture content and crook, bow, cup, and twist in inches. Where significant differences were found, Duncan's Multiple Range Test was used to array the variables in their order of importance in causing significant differences in the response under test. Two separate stacks were built at each location to replicate the experiment for purposes of estimating the error variance.

RESULTS AND DISCUSSION

Drying Rate—Lumber

The two indoor locations produced the most rapid drying rate for all species and thicknesses of lumber (table 1). Except for 8/4 white oak, all material in heated indoor locations dried below 10 percent moisture content in 90 days. As expected, the easiest to dry species of the three, silver maple, dried fastest followed closely by the moderately difficult-to-dry species, black cherry. White oak, known to be difficult to dry, was notably slower in initial drying, but the 4/4 white oak dried to less than 10 percent moisture content within 90 days. The 8/4 white oak took from 120 to more than 150 days at indoor locations to reach 10 percent moisture content.

The unheated attic with fan produced about the same drying rate as the heated indoor locations. Only small differences existed between the drying curves obtained in the heated rooms and attic, especially when these are compared to the curves obtained in the unheated locations and the freezer.

In the unheated locations, silver maple, black cherry, and 4/4 white oak took approximately 60 days to dry from the green condition to 20 percent moisture content. Indoor locations took only 30 days to produce the same moisture content drops. But once these materials were moved into heated space after 75 days at the unheated locations, they dried to 10 percent moisture content in an additional 15 days so that the total time to dry was about 90 days, essentially the same for material kept indoors. White oak of 8/4 thickness would take more than 120 days to dry to 10 percent moisture content using this two-stage drying sequence involving an unheated location followed by a heated location.

The average drying times by runs for the three species, two thicknesses, and six locations give a numerical comparison between the three main variables—species, thickness and location (table 1). A comparison of the data for the heated room and the heated room with a fan indicates that the use of a fan in a heated space only slightly increases the initial drying rate.

Table 1.—*Time required to dry green 4/4 and 8/4 white oak, black cherry, and silver maple lumber to 10 percent moisture content*[1] *at six different locations*

		Lumber						
		4/4 Thick			8/4 thick			
Location	Run	White oak	Black cherry	Silver maple	White oak	Black cherry	Silver maple	Range
	Number	*Days*						
Heated room with fan	1	62	42	32	107	90	62	32-112
	2	62	43	44	112	66	51	
Heated room	1	55	72	30	105	83	50	24-105
	2	56	42	24	79	62	55	
Unheated shed	1	100	81	80	126	107	97	80-241
	2	239	235	236	233	241	236	
Outdoors under roof	1	60	73	55	61	98	64	55-246
	2	246	240	241	232	241	246	
Unheated attic with fan	1	65	56	54	88	67	61	54-104
	2	69	58	59	104	87	62	
Freezer	1	192	182	170	217	199	180	166-228
	2	180	166	168	223	228	228	

[1] Drying times are to 15 percent moisture content for 8/4 white oak.

Wood placed in a freezer for approximately 150 days lost little moisture, especially after an initial moisture drop in the first 10 days. Upon removal from the freezer and stacking between stickers in a heated room, the material dried to 10 percent moisture content at about the same rate as green material placed directly in a heated room and no significant differences in drying defects were observed. Although Walters (1975) reported reduced drying defects in prefrozen wood, the results in this study demonstrated that prefreezing had little effect on subsequent drying characteristics.

Despite the obvious differences in drying rates between locations analysis of variance of the drying time data indicated that only species and thickness had a significant effect on drying time. Locations did not have a significant effect despite the slow drying that occurred in the freezer. The causes of this unexpected outcome were the low value for drying time in the freezer obtained by moving the material to a heated room after only 150 days and the large mean square for the error term created by differences between runs No. 1 and No. 2 at the outdoor locations. The runs were treated as replicates for purposes of estimating the error variance when, in executing the experiment, the runs actually were begun 1 week apart because of the time required to build each stack. We expected the time differential between runs to be inconsequential, but a sudden onset of cold weather occurred immediately after the first-run material reached 20 percent moisture content but before the second-run material did so. As a result, the second-run material was retained at the outdoor locations for an additional 105 days before being moved into heated space. This difference between runs in drying time produced the overestimate of the error variance that reduced the power of the treatment tests.

Although the statistical tests were impaired by the problems with the second-run material at the outdoor locations, our observations document the very slow drying rate that occurs in winter at northern latitudes (figs. 2-4). This drop in dryng rate is not unexpected because a similar set of drying curves was reported by Koch (1972) for shortleaf pine dried in an unheated shed in northern Indiana, and Rietz (1972) estimated that in the northern United States the summer drying rate for wood is six times faster than the winter rate.

Drying Rate—Cross-Sectional Disks

The disks in the heated room with fan dried somewhat faster than the lumber but, in practice, the boards and the disks should be handled the same (fig. 5). The 4/4 white oak disks, just as the 4/4 lumber, dried to 10 percent moisture content in 90 days but the 8/4 disks of white oak took more than 3 months to reach that target.

The disks held in the freezer for 13 months dropped only 10 percent in moisture content but quickly dried

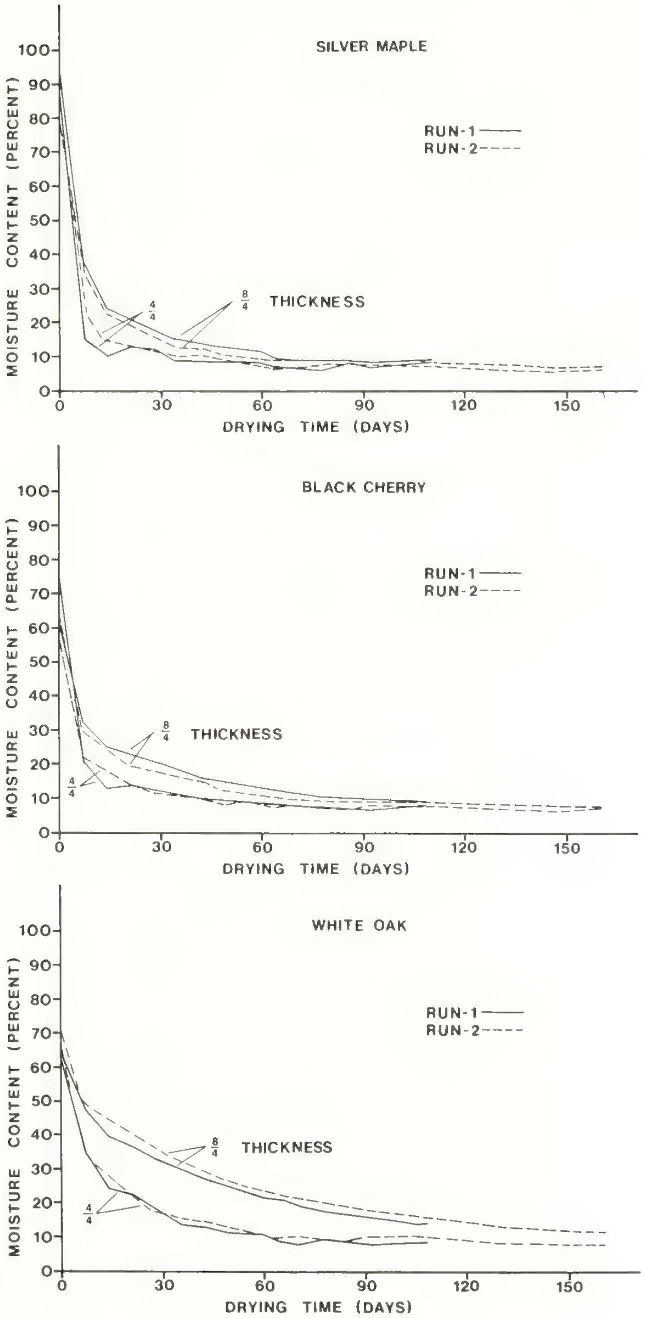


Figure 2.—*Drying curves for three species of 4/4 and 8/4 lumber in a heated room with a fan.*

to less than 10 percent moisture content when moved to a heated room (fig. 5). In this sequence of drying, the disks dried to about the same rate as the boards of the same species and thickness.

Drying Defects—Lumber

Except for a location-species interaction, there were no significant differences in the average ways of the boards between locations but there were significant differences between species and thickness in the levels of warp observed (tables 2 and 3). White oak exhibited the most bow and crook, silver maple develope, the greatest amount of twist, and black cherry and the most cup. Twist was affected also by a location-species interaction and a species-thickess interaction that was associated with the differential response of silver maple. Differences in crook and cup were significant only between species, and the Duncan's Multiple Range Test showed black cherry to have significantly less crook but more cup than the other two species.

End checking and surface checking were not severe in most instances. Surface checking appeared confined mostly to the pith and knots. Both defects occurred whenever the pith was included in the board. When the pith was near the surface, checking usually developed into splits, especially in the 8/4 lumber. White oak accounted for most of the end checking in clear wood. Surface checking in clear wood was slight, showed no consistent pattern with drying location, and was greatest in 8/4 white oak.

Case hardening was evident in all of the lumber tested. White oak, being the most refractory species of the three and having the highest shrinkage, developed the most severe case hardening at all locations. Black cherry developed moderate case hardening and silver maple only slight case hardening. Visual inspection of the qualitative data indicated no differences between thicknesses and drying location.

Volumetric shrinkage showed no significant differences between thickness or drying location, but species showed significant differences by analysis of variance. White oak decreased 10.5 percent in volume upon drying to 8 percent moisture content, but black cherry and silver maple shrunk only 8.7 percent upon drying to 8 percent moisture content. These results agree with the volumetric shrinkage published in Wood Handbook (U.S. Department of Agriculture 1972) for green-to-oven drying of these species.

Drying Defects—Cross-Sectional Disks

It is commonly known that tree-stem cross-sections develop radial splits during drying. They split because the shrinkage in circumference is disproportionately greater in wood than the shrinkage in

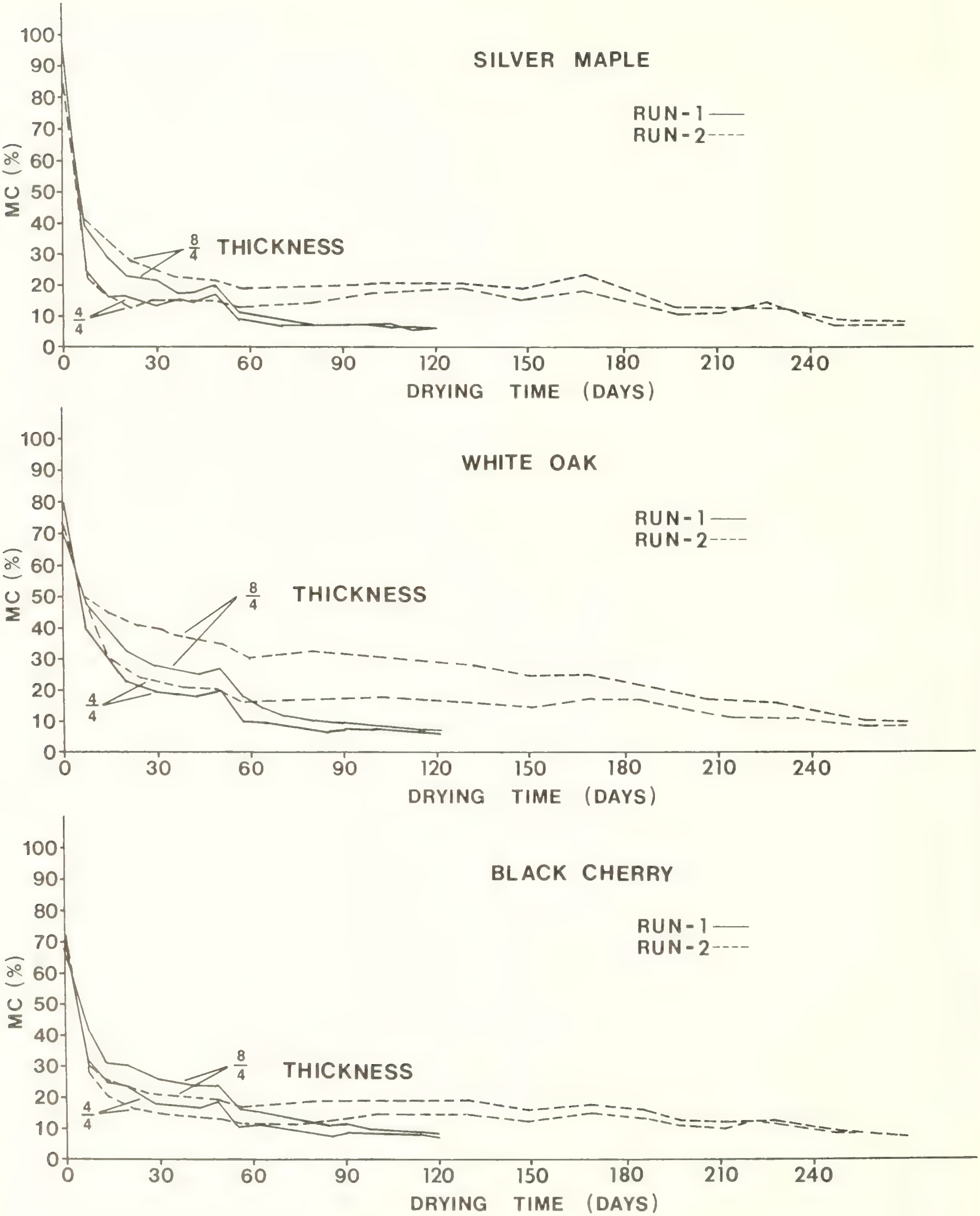


Figure 3.—*Drying curves for three species of 4/4 and 8/4 lumber kept outdoors under a roof.*

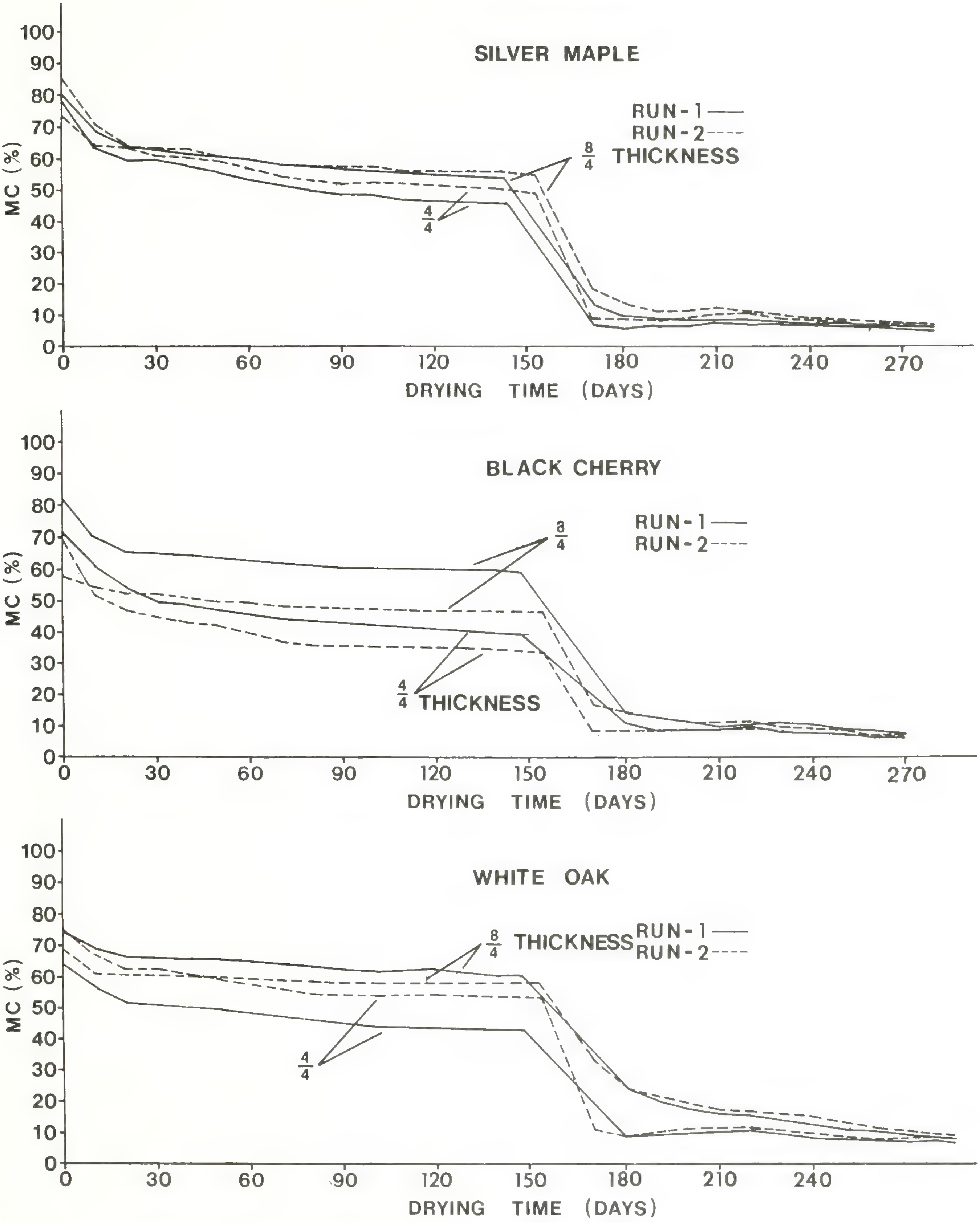


Figure 4.—*Drying curves for three species of 4/4 and 8/4 lumber kept in a freezer.*

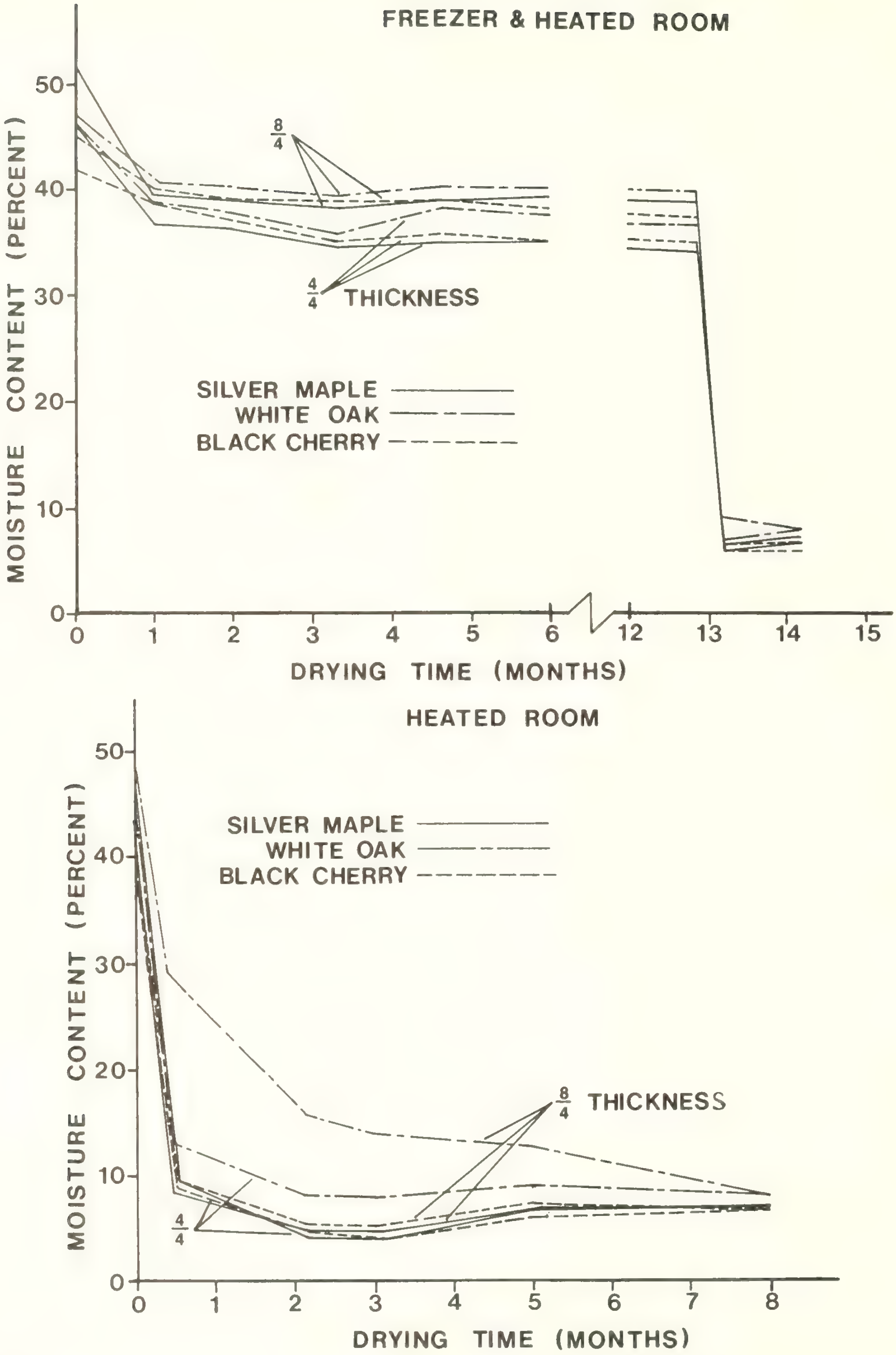


Figure 5.—*Drying curves for three species of 4/4 and 8/4 wooden disks. (A) The disks were kept in a freezer for 13½ months and then moved to a heated room. (B) The disks were kept in a heated room.*

Table 2.—*Warpage of 4/4 and 8/4 white oak, silver maple, and black cherry lumber by drying locations*[1]

Location	Species	4/4 thickness				8/4 thickness			
		Twist	Bow	Crook	Cup	Twist	Bow	Crook	Cup
		Inches							
Heated room with fan	White oak	0.24	0.60	0.66	0.20	0.13	0.46	0.56	0.07
	Silver maple	.47	.41	.51	.14	1.06	.54	.50	.12
	Black cherry	.29	.60	.45	.39	.29	.32	.34	.18
Heated room	White oak	.27	.38	.48	.13	.30	.63	.51	.12
	Silver maple	.47	.55	.53	.09	.69	.51	.57	.08
	Black cherry	.49	.43	.60	.23	.45	.39	.37	.18
Unheated shed	White oak	.32	.39	.59	.06	.24	.44	.53	.12
	Silver maple	.53	.34	.62	.13	.99	.41	.51	.11
	Black cherry	.32	.41	.44	.19	.45	.60	.45	.18
Outdoors under roof	White oak	.27	.49	.80	.06	.40	.66	.64	.03
	Silver maple	.53	.23	.49	.16	.93	.27	.49	.08
	Black cherry	.31	.37	.41	.19	.45	.48	.45	.18
Unheated attic with fan	White oak	.19	.78	.49	.10	.29	.58	.54	.08
	Silver maple	.81	.31	.58	.20	1.05	.44	.59	.05
	Black cherry	.37	.51	.46	.15	.29	.52	.47	.17
Freezer	White oak	.32	.57	.75	.04	.31	.64	.52	.18
	Silver maple	.54	.34	.50	.08	.85	.42	.43	.05
	Black cherry	.35	.38	.40	.08	.67	.32	.49	.14

[1] Average of 10 boards (5 boards per replication).

Table 3.—*Statistically significant difference for warp defects*

	Analysis of variance					
Warp defect	F value	P(F)	Source of variance	Warp defect	Duncan's Multiple Range Test $\alpha = 0.05$	
					Species	Mean value
Twist	146.16	0.0001	[1]S	Twist	White oak	0.27 [2]A
	3.84	0.0155	L*S		Silver maple	.74 B
	8.99	0.0241	T		Black cherry	.39 C
	6.16	0.0144	S*T			
					Thickness	
				Twist	4/4	.39 A
					8/4	.55 B
					Species	
Bow	1.768	0.0003	S	Bow	White oak	.55 A
	3.63	0.0190	L*S		Silver maple	.40 B
					Black cherry	.44 B
Crook	8.80	0.0044	S	Crook	White oak	.59 A
					Silver maple	.53 A
					Black cherry	.44 B
Cup	18.14	0.0002	S	Cup	White oak	.10 A
					Silver maple	.11 A
					Black cherry	.19 B

[1] S is the species, L is location, and T is thickness.

[2] Mean values followed by the same letter are not statistically significant from each other.

radius causing tensile failure perpendicular to the tangential direction. In our study white oak disks showed the smallest splits because these disks contained two piths—which reduces the length of the tangential grain to the radial grain (fig. 6, table 4). No difference was observed in the amount of splitting produced by drying in a heated room compared to drying in a freezer followed by drying to final moisture content in a heated room.

CONCLUSIONS AND RECOMMENDATIONS

The results obtained in this study demonstrate that the woodworker can dry 4/4 and 8/4 thick lumber from the green condition to 10 percent moisture content or less in 3 months. Lumber should be stacked between stickers to provide good air flow between tiers and the stack should be protected from precipitation. Because lumber dries faster at higher temperatures, the stack should be dried in warm air either by outside exposure only during the warm months of the year or by building the stack indoors in heated space during cooler months. An attic with good air flow will permit equally rapid drying if the attic temperatures are equivalent to summer air temperatures or indoor air temperatures in the heating season. Operating a fan in a heated room to accelerate drying produces little benefit.

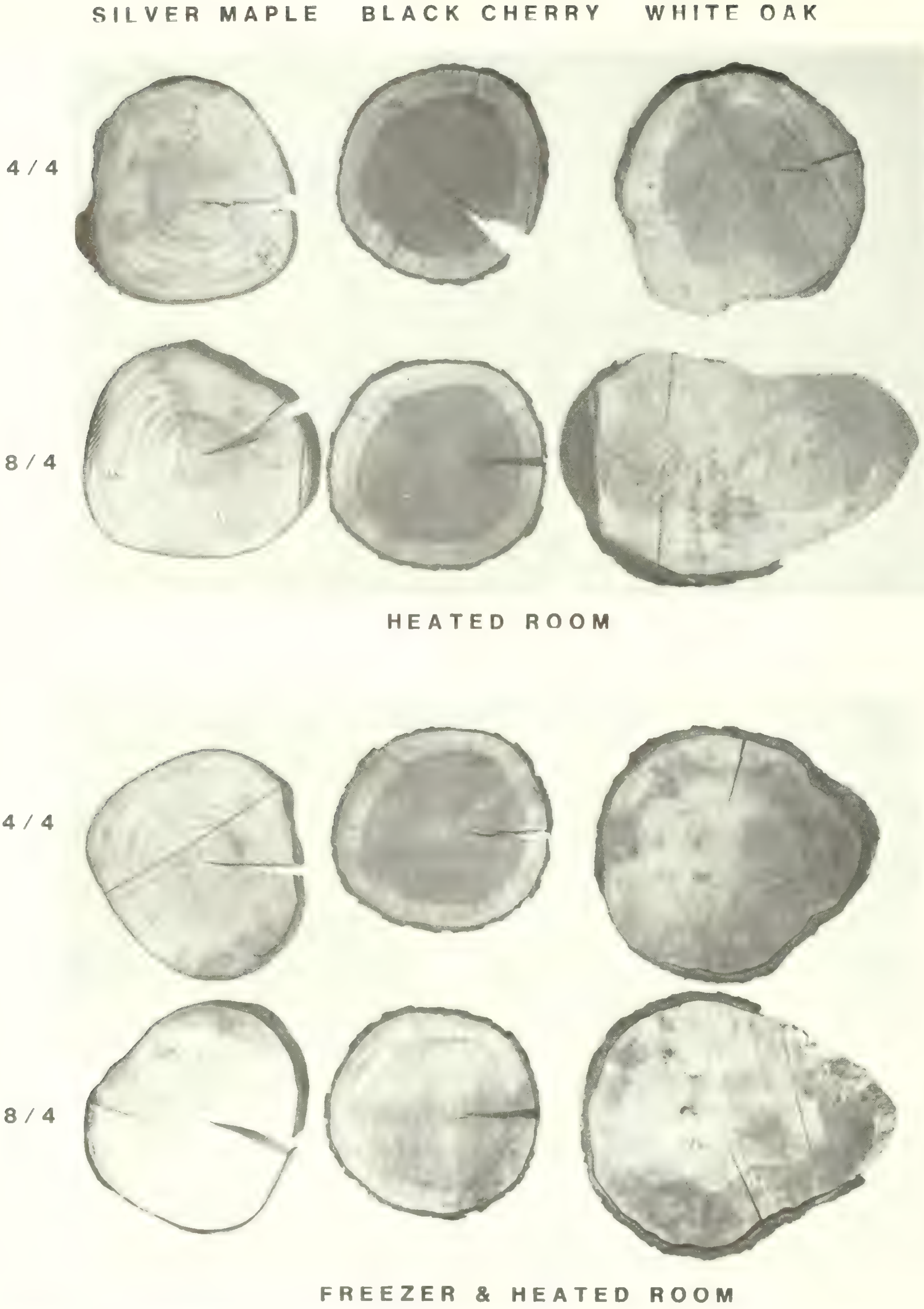


Figure 6.—*Comparison of the splits that developed in cross-sectional disks of 4/4 and 8/4 white oak, silver maple, and black cherry kept in a heated room and those kept first in a freezer and then moved to a heated room.*

Table 4.—*Comparison of dimensions of splits between the cross-sectional disks kept in a heated room and those kept first in a freezer and then in a heated room.*

Species	4/4 thickness split dimension		8/4 thickness split dimension	
	Radially	Tangentially	Radially	Tangentially
HEATED ROOM EXPOSURE ONLY				
	Inches			
Silver maple	3.4	0.6	3.5	0.6
Black cherry	3.3	.4	2.9	.3
White oak	2.8	.1	2.8	.1
FREEZING FOLLOWED BY HEATED ROOM EXPOSURE				
Silver maple	3.2	.4	3.3	.6
Black cherry	3.2	.3	3.1	.4
White oak	2.4	.1	2.8	.1

Drying is extremely slow in a freezer or at exterior temperatures near the freezing point. The woodworker who desires to dry lumber on a schedule can disregard the time that the material spends in temperatures at or near the freezing point in calculating the time required to dry to a target moisture content. Freezing before drying in a heated room does not reduce defects in the dry lumber.

When stacks are built level with sufficient top weights to keep the boards flat between stickers, drying defects will be slight. Only difficult-to-dry species will develop severe case hardening. For these species the woodworker may find it worthwhile to cut all pieces as close to final dimensions as practical so as to avoid the crook, bow, or cup that results upon resawing to width or thickness. Green lumber should be cut at least 10 percent oversize in width and thickness to allow for remachining and shrinkage during drying.

We were unsuccessful in our attempts to dry the cross-sectional disks without splitting. Splitting developed because the circumferential shrinkage of wood stems is much greater than the diameter shrinkage. Special chemical treatments such as that described by Mitchell (1963) using polyethylene glycol would enable the stem sections to be dried without splitting.

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Drying small quantities of green hardwoods at home. Res. Pap. NC-228. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 11 p.

Freshly sawn boards and stem cross-sectional disks, 4/4 and 8/4 thick, of three hardwood species were dried at six indoor and outdoor household locations in southern Illinois. It took silver maple and black cherry 90 days and white oak from 90 to 150 days to dry to less than 10 percent moisture content at the indoor locations.

KEY WORDS: Lumber, warpage, defects, checking, *Prunus serotina, Acer saccharinum, Quercus alba.*

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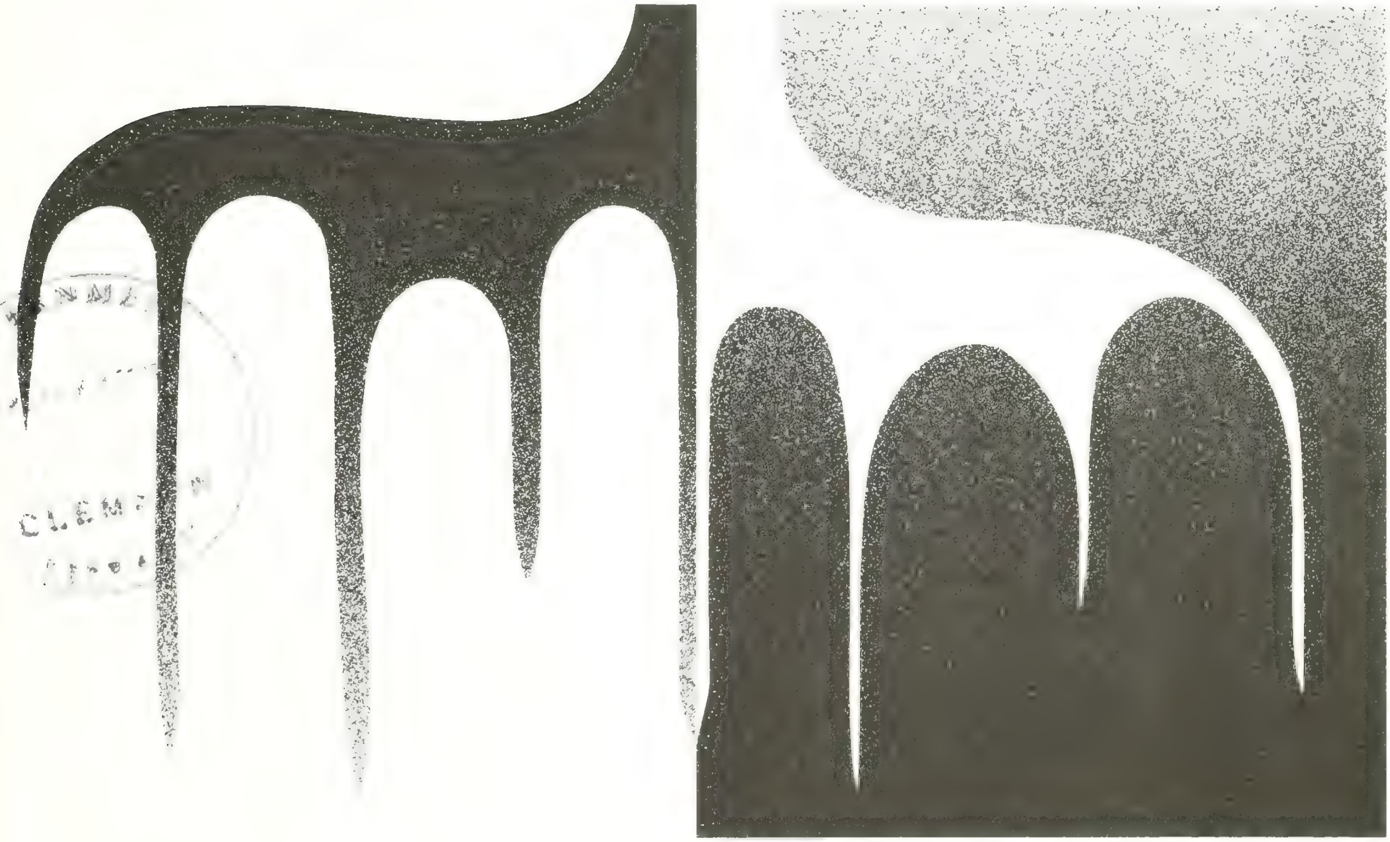
Control of Black Walnut Root Rot Diseases in Nurseries

Kenneth J. Kessler, Jr.



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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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CONTROL OF BLACK WALNUT ROOT ROT DISEASES IN NURSERIES

Kenneth J. Kessler, Jr., *Principal Plant Pathologist,*
Carbondale, Illinois

Historically, root rots have been one of the most serious pest problems nursery managers have confronted. As recently as 1977 a survey of 99 public and industrial nurseries in the United States reported that more than 85 percent had root rot problems requiring chemical or cultural control (Abbot and Fitch 1977). As energy costs have increased, production costs for nursery stock have increased correspondingly. Growing costs in 1977 for northeastern State nurseries averaged $22 per thousand for 1-0 stock (Abbott and Fitch 1977). Allison and Bridgewater (1977) found that for 18 eastern State nurseries growing 1-0 black walnut stock, dollar losses attributable to root rot averaged 17 percent of total production costs.

In recent years much of the research effort on walnut root rots has been concentrated on *Cylindrocladium* and *Phytophthora* root rots. Roth and Griffin (1979) studying *Cylindrocladium* in Virginia, and Cordell (1976) in North Carolina and Green and coworkers (Green 1975, Ploetz and Green 1977) studying *Phytophthora citricola* in Indiana have led the effort. Because control of most root rots involves destroying or reducing populations of pathogen propagules in the soil, much of the research on root rot control of other species also is relevant to black walnut.

This report first discusses the black walnut nursery ecosystem and the principal root rot pathogens in the eastern United States. The report then describes the present status of nursery root rot management and gives some conclusions and recommendations for future research.

THE WALNUT NURSERY ECOSYSTEM

The walnut nursery system has evolved into factorylike production that often seems to emphasize quantity at the expense of quality. Some especially notable features of the production system are dense planting of seed in nursery beds, routinely fumigating soils before planting, and mechanically lifting stock.

Walnut seed is usually collected in the fall and shortly after is planted in nursery seedbeds. Because seed generally germinates at a rate of 50 percent or less (Brinkman 1974), it must be planted at a dense enough rate to allow for a final seedling concentration of around 8 per square foot. Black walnut seed requires cold stratification for 3 to 4 months. Even under optimal stratification conditions the seed has a tendency to germinate over an extended period from April to mid-summer. During stratification seedbeds may be covered with screens to exclude rodents and with several kinds of mulch materials to minimize the harmful effects of alternate freezing and thawing. Commonly used nursery organic soil amendments include sawdust, peat, manure, rotted bark, wood chips, and mushroom compost (Abbott and Fitch 1977). Seed stratified overwinter in cold storage facilities or in outdoor pits is sometimes spring planted.

Sufficient growth to permit outplanting for 1-year-old seedlings requires that the embryos remain attached to their cotyledons during the early developmental period. Detachment from the cotyledons or loss of cotyledons through attack by rot organisms can reduce growth 50 percent or more.

Most nurseries plant cleaned seed after the hulls have been removed by mechanical hullers. In the course of mechanical hulling, shells of some seed may become chipped and cracked providing entry courts for pathogens. Following hulling, seeds are floated on water to detect unfilled seed.

After germination, height growth begins slowly but soon assumes a rapid rate and is essentially completed within 2 months (Schlesinger and Funk 1977).

Diameter growth continues after height growth terminates and may continue into late summer. Root growth ends in early fall around the time leaves are becoming senescent prior to being shed. Black walnut loses its leaves earlier in the fall than most other tree species. The growth period varies from 90 to 135 days from north to south over its range.

Initially, the development of the seedling taproot is more rapid than that of the corresponding stem. Lateral roots soon form on the taproot and an extensive system of primary and secondary roots develops. Initially, roots are devoid of mycorrhizal infection. Gradually, the root system becomes infected with endotrophic mycorrhizal fungi. In some nurseries where soils are fumigated prior to planting, many roots may remain uninfected by mycorrhizal fungi. In well-drained nursery soils taproots may extend several feet deep. During lifting the portion of the taproot below about 1 foot is severed and remains in the soil. Some nurseries use a cutting device to prune root systems midway through the season to encourage a compact root system more suitable for transplanting. Taproot length also can be regulated somewhat by controlling irrigation.

Although walnut trees develop best on deep, well-drained, moist fertile soils, seedlings can develop on less favorable nursery soils as long as the soils drain well. Nursery soils with nutrient and humus imbalances can be carefully manipulated to serve as adequate substrates for growing black walnut seedlings.

Seedbed preparation often begins with cover cropping the planting area 1 year before planting the seeds. Cover crops include rye, sudan grass, peas, oats, soybeans, sorghum, millet, wheat, vetch, and alfalfa (Abbott and Fitch 1977). After incorporating the cover crop and before planting, the soil is generally fumigated to eliminate weed seeds as well as to control fungal pathogens and parasitic nematodes. Although fumigation may eliminate pathogen propagules in treated nursery soil, they can sometimes be quickly reintroduced from contaminated irrigation water (Shakes and McCarter 1979). Fumigation has greatly reduced the need for cultivation during the summer months, although some hand weeding may be required. Walnut nursery beds are routinely irrigated as needed.

At some nurseries walnut stock is lifted in the fall and kept in cold storage facilities or heeling-in areas out of doors. Fall lifting is useful if spring lifting is difficult either because of other higher spring nursery priorities or to avoid excessively wet field conditions.

Bed planting of walnut where the foliage of individual seedlings creates an unbroken bed cover creates a humid leaf zone area susceptible to infection by leaf pathogens such as the anthracnose fungus, *Gnomonia leptostyla*.

THE ROOT ROT ORGANISMS

Phytophthora

The *Phytophthora* species associated with black walnut in nurseries are *P. cinnamomi* (Crandall *et al.* 1945), *P. cactorum* (Crandall and Hartley 1938) and *P. citricola* (Ploetz and Green 1977). The root rots caused by *Phytophthoras* are primarily of concern during cool, wet weather. *Phytophthora* fungi produce spores capable of moving long distances in the soil. Nutrients exuded from roots of host plants attract the motile spores. After reaching the surface of a root, the spore is inactive for a brief period before it releases enzymes that dissolve epidermal cell walls. At this point it rapidly invades the root and under continuing cool conditions adjoining portions of the root system are invaded until entire root systems are colonized. Depending on the *Phytophthora* species involved, a number of spore types are produced. These spores, some of which develop in the root rhizosphere while others develop in the roots, can survive for 1 or more years under conditions varying from a moist, cool soil (Zentmeyer and Mircetich 1966) to a dry warm soil (Hoppe 1966). The germination of these dormant spores requires favorable soil conditions plus the presence of substances exuded by host roots.

Cylindrocladium

Cylindrocladium scoparium, C. floridanum, and *C. crotalariae* attack black walnut (Roth and Griffin 1979). These fungi do not produce motile spores but spread to a limited extent through the soil by hyphal threads, the mycelium. Generally the hyphae originate from sclerotia, small dormant structures in the soil. The sclerotia may be visible to the naked eye and resemble small aggregated sand particles. The *Cylindrocladium* fungi prefer warm soil conditions and thus are a more serious problem in southern nurseries. *Cylindrocladium* strains adapted to cooler soils have been associated with nursery root rots in northern nurseries, however (Bugbee and Anderson 1963, Thies and Patton 1970). Because their resting structures, the sclerotia, are large and possess cells resistant to chemical attack, they are difficult to eliminate from soil by chemical sterilization techniques.

Pythium

These fungi, which typically cause damping-off diseases of seedlings, were associated with a root rot of 2-year-old outplanted walnut seedlings in Louisiana. Infection of the seedlings was associated with high population levels of *Pythium* spp. in the originating nursery (Affeltranger *et al.* 1980). *Pythiums* and *Phytophthoras* are closely related and both belong in the fungus family, Pythiaceae.

Sclerotium and *Phymatotrichum*

Sclerotium rolfsii (Pellicularia rolfsii) and *Phymatotrichum omnivorum* root rots occasionally affect black walnut in southern United States nurseries (Ezekiel and Nelson 1941, Streets and Bloss 1973). Like *Cylindrocladium* spp., these fungi produce sclerotia as survival propagules in the soil. Development and survival of *S. rolfsii* and *P. omnivorum* require warm soils. *Phymatotrichum* root rot is largely confined to alkaline, calcareous soils.

PRESENT STATUS OF THE ROOT ROT MANAGEMENT SYSTEM

Biological Monitoring

It has been difficult to attribute walnut root rot injury in nurseries to specific causal agents. A principal problem has been the lack of a universal scheme for comparing the incidence of the several walnut root pathogens in particular nurseries. Pathologists with specific expertise in particular pathogens often have conducted surveys emphasizing either *Cylindrocladium* or *Phytophthora.*

Population counts of pathogen propagules in soil prior to planting seem to be of little use. Such populations vary drastically in response to soil conditions such as temperature and moisture and independently from the presence of host plants (Schmitthenner 1970). Severe outbreaks of *Cylindrocladium* root rot have occurred in nurseries with low soil populations of infectious propagules (Roth and Griffin 1979).

Disease symptoms, the use of highly susceptible species as trap crops, and population counts of the fungi responsible are the principal means of following the development of outbreaks.

The *Phytophthora* root rot symptoms differ somewhat from *Cylindrocladium* root rot particularly in the early stages of development. *Phytophthora* lesions first appear as water-soaked, greenish black discolorations usually located at the root collar (Green 1975). *Cylindrocladium* lesions are at first small and blackish and are scattered over the laterals as well as the taproot. Later the lesions may coalesce and engulf the whole taproot and look much like a well-developed *Phytophthora* infection. Longitudinal cracking of the taproot often occurs with *Cylindrocladium* infections, but such cracking occurs less often with *Phytophthora* infections (Cordell and Skilling 1975, Roth and Griffin 1979). Severely rotted seedlings may have wilting and chlorotic foliage with both *Phytophthora* and *Cylindrocladium* infections.

Geranium leaf, azalea leaf, and alfalfa seedling traps appear to be the methods of choice for bioassaying walnut nursery soils for the presence of *Cylindrocladium* (Newhouse and Hunter 1980, Linderman 1972, Thies and Patton 1966). These methods produce general information on numbers of trap plants attacked and more specific information on particular *Cylindrocladium* spp. involved when the fungi are isolated using specific media.

Wet-sieving soils to recover microsclerotia of *Cylindrocladium* spp. has been used to obtain population counts of these primary infectious propagules (Thies and Patton 1970a). Because of the microsize of *Phytophthora* propagules, no comparable method exists for them.

Several specific isolation media have been developed to increase the recovery efficiency of *Cylindrocladium* and *Phytophthora* from soils and infected roots. The better *Phytophthora* isolation media utilize polyene antibiotics such as nystatin, which *Phytophthora* spp. tolerate well but which inhibits most other fungi (Flowers and Hendrix 1969). Cultural media specific for *Cylindrocladium* have also been developed (Krigsvold and Griffin 1975, Griffin 1977). These contain thiabendazole and quaternary ammonium compounds as suppressants of other competitive fungi. A summary of methods for differentiating between *Cylindrocladium* and *Phytophthora* root rot diseases is presented below:

	Phytophthora	*Cylindrocladium*
I. Symptoms	Water-soaked greenish discolorations at root collar.	Scattered lesions on laterals as well as taproots. Longitudinal cracking of taproots.
II. Detection in soil with trap plants	Citrus fruit Apple fruit	Azalea and geranium leaves. Alfalfa seedlings.
III. Recovery of propagules from soil	—	Wet-sieving and den settling in water.
IV. Isolation from soil and infected tissue onto culture media	Media containing polyene antibiotics.	TBZ medium. Sucrose-QT medium.

Cultural Management of Disease

Some promising experiments have been conducted on the effects of organic materials added to the soil on reducing root rots. Cotton wastes as a soil amendment gave good control of *Phytophthora* root rot of avocado under laboratory conditions (Zentmeyer 1963). Alfalfa meal was also good. These materials produced an ammonium level in the soil that was toxic to the *Phytophthora* fungus. Hadi (1974) reduced Cylindrocladium root rot propagules in soil by planting flax or sorghum-sudangrass cover crops the year before tree planting.

Selecting the best nursery planting locations for black walnut helps minimize root rot problems. Lowlying, heavy, poorly drained soils should be avoided (Green 1975) because their impaired drainage provides good conditions for disease propagules to survive and germinate.

Tiling of medium to light soils to improve drainage is helpful. On heavier soils tiling has not been as helpful except close to the drainage tiles (Wilkinson and Millar 1981).

Selection of seed planting date suggests itself as a root rot avoidance strategy. If seed can be held in cold storage until late spring or early summer, it should be possible to avoid the dangerous spring period with its moist soils most favorable to root rot development. The determinate growth pattern of black walnut with the ability of germinated black walnut seed to produce good-sized seedlings in a few months should allow for the development of adequate-sized seedlings following late planting.

Fertilization with chemical fertilizers has not had much effect on walnut root rot incidence in nurseries.

Flooding has been successfully used to kill resting structures of root rot organisms in the soil (Moore 1949, Stoner and Moore 1953). However, most walnut nurseries cannot be easily flooded. When picking new nursery locations, consideration could be given to sites amenable to periodic flooding if so desired.

Solar heating soils to kill pathogen propagules appears promising as a safe, relatively inexpensive control method (Ashworth 1980, Elad *et al.* 1980, Grinstein *et al.* 1979, Katan *et al.* 1976, Pullman and Devay 1977, Stapleton and Devay 1980). The method has given best results with soils kept moist by trickle irrigation under clear plastic tarps maintained in place for from 3 to 5 weeks. Pullman and Devay (1977) reduced pathogen propagules by 72 percent and annual winter weeds by 92 percent with plastic tarps. Highest temperatures reached were 43°C (109°F) at a 6-inch soil depth and 55°C (131°F) at a 2-inch soil depth.

Biological Control

Many examples have been found of soil fungi, bacteria, and actinomycetes parasitizing dormant propagules, germinating spores, and active mycelium of root pathogens in soil (Ayers and Adams 1979a, 1979b, Ayers and Lumsden 1977, Broadbent *et al.* 1971, Elad *et al.* 1980a, Hoch and Abawi 1979, Huang 1977, Kelly 1976, Sneh *et al.* 1977, Turner and Tribe 1976, Wells *et al.* 1972). However, many of the studies were done under unnatural conditions in the laboratory or greenhouse and a few attempts have been made to apply the experimental findings to control in the field. The principal reason for this seems to be that laboratory conditions required for successful biological control, although achievable in the field, are too costly to be practical. For example, Wilhelm (1951) determined that to translate one successful laboratory study to control *Verticillium* wilt in the field would require 1.5 tons of an organic soil amendment such as cottonseed meal per acre foot of treated soil.

The practically routine practice of fumigating nursery soils provides particularly favorable conditions for introducing and increasing numbers of parasites that attack root rot pathogens. Many laboratory biological control studies noted a favorable affect of steam sterilization on populations of particular mycoparasites (Broadbent *et al.* 1971). Parasites with good saprophytic competitive ability to colonize soil organic matter should be especially favored following fumigation.

Best opportunities for biological control are probably in the upper soil profile where gas concentrations, temperature, and moisture conditions are most favorable for biological activity. Little is known of the presence of parasites favored by anaerobic or poorly aerated soil conditions. But recent finding of amoeboid parasites of soil pathogens indicates that other types of parasites may be found if unusual soil conditions are searched in the right way (Homma *et al.* 1979).

Chemical Management

Fumigants such as methyl bromide are routinely used to control or eliminate root rot pathogens and weed seeds from nursery soils. Nurseries in which nematodes are a problem may be fumigated with pre- and post-emergence nematocides, which may indirectly provide some root rot control through reducing the number of nematode root wounds that can serve as entry points for pathogens (Diomande and Beute 1979).

PRESENT STATUS OF INTEGRATED PEST MANAGEMENT

Soil fumigation has been the most useful technique for controlling root rot pathogens. Recently fumigated soil appears to provide a most suitable environment for introducing microorganisms with biological control potential into the nursery ecosystem with better than average chances to maintain them at levels adequate for good control results.

Many of the cultural practices used in nurseries, arrived at empirically, may provide some root rot control. Avoiding poorly drained soils reduces the opportunities for optimum moisture conditions favoring root rot organisms (Pratt 1974). Planting densities that allow for some seedling loss, particularly through pre-emergence mortality, help to maintain adequate stocking of nursery beds. Monitoring bed moisture levels and only irrigating when absolutely necessary helps to maintain soils at submoisture saturation levels less favorable for root rot pathogens. Crop rotation, fallowing, and monoculturing may regulate pathogen populations in some nurseries. Hard evidence on the effects of these practices is not available, however.

Grading to remove severely affected seedlings prior to shipping is useful. Moderately affected seedlings often will recover when outplanted (Hansen *et al.* 1980, Smith 1967).

RECOMMENDATIONS

Research on walnut root diseases has been episodic and often in response to crisis situations. Occasional broad surveys such as Cordell's (Cordell 1973, Cordell 1976, Cordell and Matuszewski 1974) give some indication of the impact of specific root rot diseases on walnut seedling production. Much of the research effort has emphasized life history and chemical control. New studies that integrate chemical, biological, and cultural control promise to be particularly fruitful. Such studies require the cooperation of extension service pathologists to monitor disease and pathogen development, research pathologists to establish experiments, and nursery managers to provide and maintain experiments under nursery conditions. Pathogen and biological control agent populations in particular need to be related to cultural practices and nursery soil types and microclimates. Some specific studies recommended for initiation are:

1. Effect of seed planting date on root rot development.
2. The introduction of biological control agents into recently fumigated soils.
3. Methods for deeper soil application of fumigants to control *Cylindrocladium* root rot.
4. Solar fumigation of soils.
5. Selection and maintenance of soils naturally suppressive to root rot (Broadbent and Baker 1973, Toussoun 1973).
6. Effect of soil flooding during fallow period preceding planting.
7. Effect of walnut monoculture on pathogen populations (Shipton 1973).
8. Effects of organic amendments (cover crops, compost, sewage sludge, etc.) on pathogen populations (Hoitink 1976, 1977).
9. Effect of planting in raised beds on root rot severity (Benson and Jones 1979).
10. Establishment of an annual industry-wide survey of root rot losses attributable to specific pathogens to be maintained for several years to provide baseline data.

In the absence of sophisticated integrated control procedures for black walnut root rots, the following procedures are advised:

1. Fumigate problem soils. Closely follow directions for particular fumigant used. Pay special attention to proper soil temperature, moisture, and tilth. *Cylindrocladium* sclerotia within dry soil clods are especially difficult to fumigate. Rototill cloddy soils to reduce soil particle size for better fumigant penetration.
2. Avoid or correct drainage of chronically wet nursery beds.
3. Grade lifted seedlings from rot-affected beds. Eliminate seedlings with upper part of taproot severely rotted. Seedlings with a rotted taproot tip or partially rotted laterial roots often will recover when outplanted.
4. Maintain good nursery records. Note practices, particularly cultural, that appear to affect root rot incidence. Follow up with pilot testing of these procedures.
5. Irrigate only when absolutely necessary and allow soils to dry before re-irrigating. Remember that black walnut is taprooted and can tolerate moisture stress better than many other hardwoods.
6. Avoid bringing nursery stock and machinery from other nurseries into clean nurseries.

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Control of black walnut root rot diseases in nurseries. Res. Pap. NC-229. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 8 p.

Current nursery methods used to control black walnut root rot diseases are considered in terms of integrated pest management. Suggestions for future root rot control research studies and procedures to minimize root rot problems are provided.

KEY WORDS: *Juglans nigra, Phytophthora, Cylindrocladium, Pythium, Sclerotium, Phymatotrichum,* fumigation, biological control.

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Green Above-Stump Weights for Red Oak, Red Maple, and White Birch

in Northern Michigan

Helmuth M. Steinhilb, Edwin S. Miyata, and Thomas R. Crow

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GREEN ABOVE-STUMP WEIGHTS FOR RED OAK, RED MAPLE, AND WHITE BIRCH IN NORTHERN MICHIGAN

Helmuth M. Steinhilb, *Research Forester,*
Edwin S. Miyata, *Research Industrial Engineer,*
Houghton, Michigan,
and **Thomas R. Crow,** *Research Forest Ecologist,*
Marquette, Michigan

The trend toward more fully mechanized whole-tree chipping has created a need for information concerning green tree weights. For example, it is presently common to use net green weight of chips as a measurement for the basis of payment to the logger in whole-tree harvesting, rather than cord, board-foot, or cubic-foot measures.

Green weight tables for the above-stump portions of trees by species, d.b.h., and tree height are necessary to obtain preharvest estimates of biomass to be removed from the forest in chipping operations. Such tables are also essential for studying the cost and productivity of the felling/bunching, skidding, chipping, and transporting phases of chip-harvesting operations. Therefore, green weight tables are becoming a required tool for studying and analyzing whole-tree logging operations.

Weight tables for several tree species have been published for areas outside the Lake States. Young's work in Maine (Young *et al.* 1980), Monteith's in New York (Monteith 1979), and Moehring's in the South (Moehring *et al.* 1973) provide excellent information for biomass research and logging applications. Green-weight tables for the above-stump portions of five northern Michigan tree species have been published (Steinhilb and Erickson 1970, 1972; Steinhilb and Winsauer 1976; Winsauer and Steinhilb 1981). This paper provides above-stump green-weight information, including foliage, for three additional northern Michigan species commonly chipped for fiber and energy production: red oak (*Quercus rubra),* red maple (*Acer rubrum),* and white birch (*Betula papyrifera).*

THE STUDY

Two mixed hardwood stands containing pole-sized and small sawtimber trees were selected for study in Baraga County, Michigan. These stands had an average basal area of 105 sq ft/acre (24.15 m/ha) in trees 2 inches (5.1 cm) d.b.h. and larger. Tree d.b.h. ranged from 2 inches (5.1 cm) through 20 inches (50.8 cm), with an average d.b.h. of 4.8 inches (12.2 cm). The most prevalent tree species were red maple, red oak, quaking aspen (*Populus tremuloides),* and white birch, with smaller amounts of red (*Pinus resinosa)* and white pine (*P. strobus),* sugar maple (*Acer saccharum),* yellow birch (*Betula alleghaniensis),* and hemlock (*Tsuga canadensis).* Age of the stands was 65 years. Site index was 60 for both red oak and red pine.

Personnel from the Forestry Sciences Laboratories at Marquette and Houghton, Michigan, and the School of Forestry and Wood Products at Michigan Technological University, Houghton, Michigan, cooperated to conduct the study in the fall of 1980. The Pettibone Corporation[1] of Baraga, Michigan, provided a rubber-tired cable skidder to move the trees from the stump to the weighing area.

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[1] *The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.*

FIELD PROCEDURES

All red maple, red oak, and white birch trees within 5 feet of transects that were run through the stands were numbered with paint; species and d.b.h. were recorded. From the list of recorded trees, 30 to 40 trees of each species were selected for weighing; an attempt was made to select approximately equal numbers of trees (three to four) in each diameter class. Data were collected for 36 red oak, 33 white birch, and 48 red maple trees (table 1). Sample trees were felled by a chain saw and skidded to a nearby open area for weighing.

The height of each tree from butt to tip and the bole length from butt to a 4.0-inch (10.2-cm) top diameter outside bark was measured and recorded. The entire above-stump portion of the tree was then weighed within a few hours of felling by suspending it from a knuckle boom loader mounted on a small wheeled skidder (fig. 1). The loader boom was equipped with a load cell located between the log grapple and the boom. (The load cell had an accuracy of ±0.5 percent of the load being weighed.) The tree was then lowered to the ground, all limbs removed from the bole, and the top severed at 4.0 inches (10.2 cm) diameter outside bark. The delimbed bole was then suspended and the green weight recorded. The difference between the above-stump tree weight and the bole weight was considered to be residue weight.

DEFINITIONS

Above-stump weight—The green weight of wood, bark, and foliage of the above-stump portion of the tree.

Table 1.—*Range of field data*

	Red maple	Red oak	White birch
D.b.h. (in.)	2.0–16.8	3.4–17.1	1.6–15.6
D.b.h. (cm)	5.1–42.7	8.6–43.4	4.1–39.6
Tree height (ft)	22–81	25–74	22–85
Tree height (m)	6.7–24.7	7.6–22.6	6.7–25.9
Green tree weight (lb)	30–4,352	60–4,738	5–3,190
Green tree weight (kg)	14–1,974.0	27.2–2,144.6	2–1,447
Bole length (ft)	7–67	10–60	3–58
Bole length (m)	2.1–20.4	3–18.3	9–17.7
Green bole weight (lb)	53–3,163	86–2,956	25–2,258
Green bole weight (kg)	24–1,434.7	39–1,340.8	11–1,024.2

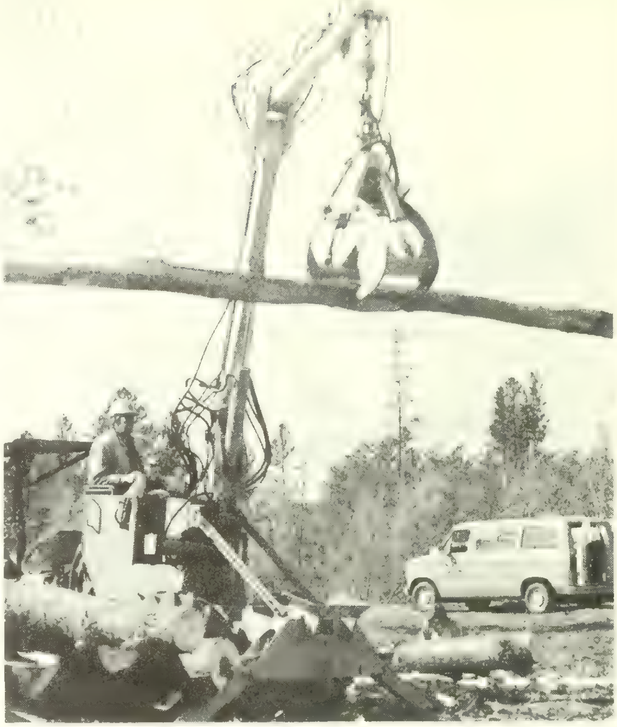

Figure 1.—*Method and equipment for weighing trees.*

Bole weight—The green weight of the wood and bark of the delimbed tree bole from butt to 4 inches diameter outside bark.

Residue weight—The green weight of wood, bark, and foliage of all limbs removed from the bole and the top of the tree from a diameter of 4 inches outside bark to the tip.

ANALYTIC PROCEDURE

The data for each species were analyzed separately for above-stump green weight, bole green weight, and residue green weight. The form of the estimating equations was:

Green weight of component = $A + B\,(\text{d.b.h.})^2\,(\text{tree height})$.

Table 2 gives the estimating equations and standard errors of estimate.

RESULTS

The green above-stump tree weights, bole weights, and residue weights for red oak are presented in table 3, red maple in table 4 and values for white birch in table 5. The area inside the lines in each table comprises the range of the field data.

Table 2.—*Regression equations for estimating above-stump green weight of trees, boles, and residues for red oak, red maple, and white birch*

Green weight (Y) (In pounds)	**Regression equation**	**Standard error**	**Number of trees sampled**
	RED OAK		
Tree weight, including foliage	$Y = 2.7 + 0.198\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.18\,(\text{d.b.h.})^2$	36
Bole weight to 4-inch top	$Y = -28.0 + 0.158\,(\text{d.b.h.})^2\,(\text{tree height})$	$0.85\,(\text{d.b.h.})^2$	34
Residue weight, including foliage	$Y = 19.0 + 0.044\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.22\,(\text{d.b.h.})^2$	33
	RED MAPLE		
Tree weight, including foliage	$Y = 19.9 + 0.164\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.45\,(\text{d.b.h.})^2$	48
Bole weight to 4-inch top	$Y = -16.8 + 0.127\,(\text{d.b.h.})^2\,(\text{tree height})$	$0.87\,(\text{d.b.h.})^2$	30
Residue weight, including foliage	$Y = 46.2 + 0.034\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.16\,(\text{d.b.h.})^2$	30
	WHITE BIRCH		
Tree weight, including foliage	$Y = 8.7 + 0.173\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.91\,(\text{d.b.h.})^2$	33
Bole weight to 4-inch top	$Y = -35.9 + 0.137\,(\text{d.b.h.})^2\,(\text{tree height})$	$0.93\,(\text{d.b.h.})^2$	25
Residue weight, including foliage	$Y = 36.2 + 0.038\,(\text{d.b.h.})^2\,(\text{tree height})$	$1.16\,(\text{d.b.h.})^2$	25

Table 3.—*Red oak green weights (values inside the lines show the range of the sample data)*

D.b.h class (inches)	**Tree height (feet)**						
	20	30	40	50	60	70	80
	Green tree weight (pounds)						
2	19	26	34	42	50		
4	66	98	129	161	193	224	
6	145	217	288	359	430	502	573
8		383	510	636	763	890	1016
10		597	795	993	1191	1389	1587
12			1143	1428	1713	1999	2284
14			1555	1943	2331	2719	3107
16			2030	2537	3044	3551	4058
18			2569	3210	3852	4493	5135
20				3963	4755	5547	6339
	Green bole weight (pounds)						
6		143	200	256	313	370	
8		275	376	478	579	680	781
10		446	604	762	920	1078	1236
12			882	1110	1337	1565	1792
14			1211	1520	1830	2140	2449
16			1590	1994	2399	2803	3208
18			2020	2532	3044	3555	4067
20			2500	3132	3764	4396	5028
	Green residue weight (pounds)						
6		67	82	98	114	130	
8		103	132	160	188	216	244
10		151	195	239	283	327	371
12			272	336	399	463	526
14			364	450	536	623	709
16			470	582	695	807	920
18			589	732	874	1017	1159
20			723	899	1075	1251	1427

Table 4.—*Red maple green weights (values inside the lines show the range of the sample data)*

D.b.h. class (inches)	**Tree height (feet)**						
	20	30	40	50	60	70	80
	Green tree weight (pounds)						
2	33	40	46	53	59		
4	72	99	125	151	177		
6	138	197	256	315	374	433	492
8	230	335	440	545	650	755	860
10	348	512	676	840	1004	1168	1332
12		728	965	1201	1437	1673	1909
14		984	1306	1627	1949	2270	2591
16			1699	2119	2539	2959	3379
18				2677	3208	3739	4271
20				3300	3956	4612	5268
	Green bole weight (pounds)						
6		120	166	212	258	303	
8		227	308	390	471	552	633
10		364	491	618	745	872	999
12		532	715	898	1080	1263	1446
14			979	1228	1477	1726	1975
16			1284	1609	1934	2259	2584
18				2041	2452	2864	3275
20				2523	3031	3539	4047
	Green residue weight (pounds)						
6		83	95	107	120	132	
8		111	133	155	177	199	220
10		148	182	216	250	284	318
12		193	242	291	340	389	438
14			313	379	446	513	579
16			394	481	568	655	743
18				597	707	817	927
20					862	998	1134

Table 5.—*White birch green weights (values inside the lines show the range of the sample data)*

D.b.h. class (inches)	Tree height (feet)						
	20	30	40	50	60	70	80
	Green tree weight (pounds)						
2	23	29	36	43	50		
4	64	92	119	147	175		
6	133	196	258	320	382	445	507
8	230	341	452	562	673	784	894
10	355	528	701	874	1047	1220	1393
12		756	1005	1254	1503	1753	2002
14		1026	1365	1704	2043	2382	2721
16		1337	1780	2223	2666	3109	3552
18			2251	2811	3372	3932	4493
20				3469	4161	4853	5545
	Green bole weight (pounds)						
6		112	161	211	260	309	
8		227	315	403	490	578	
10		375	512	649	786	923	1060
12		556	753	951	1148	1345	1542
14		770	1038	1307	1575	1844	2112
16			1367	1718	2068	2419	2770
18			1740	2184	2627	3017	3515
20			2156	2704	3252	3800	4348
	Green residue weight (pounds)						
6		77	91	105	118	132	
8		109	133	158	182	206	231
10		150	188	226	264	302	340
12		200	255	310	365	419	474
14			334	409	483	558	632
16			425	523	620	717	814
18			529	652	775	898	1021
20			644	796	948	1100	1252

The reader is cautioned to use the tables with care, since they were constructed from samples of only 25 to 48 trees of each species collected from a limited area in Baraga County, Michigan. The most accurate estimates of biomass will probably result when the tables are applied to stands similar in age, composition, tree size, and site index.

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Steinhilb, Helmuth M.; Miyata, Edwin S.; Crow, Thomas R.
Green above-stump weights for red oak, red maple, and white birch in northern Michigan. Res. Pap. NC-230. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 4p.

Presents the green weights of the above-stump portion of trees, boles, and residue for red oak, red maple, and white birch in northern Michigan. Estimating equations and green weight tables are included for the tree components of each species.

KEY WORDS: Red oak, red maple, white birch, tree, bole, residue, mechanized harvesting.

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Biomass Production of 4- to 9-Year-Old Intensively Cultured Larix Eurolepis Growth

in "Scotch Plaid" Plots in Wisconsin

J. Zavitkovski, Allen L. Lundgren, and Terry F. Strong

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Zavitkovski, J.; Lundgren, Allen L.; Strong, Terry F.
Biomass production of 4- to 9-year-old intensively cultured *Larix eurolepis* grown in "Scotch Plaid" plots in Wisconsin. Res. Pap. NC-231. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 10 p.

Intensively cultured *Larix eurolepis* at age 9 averaged 7.6 m in height and, depending on the spacing, 2.3 to 6.4 cm in d.b.h. The total stem-branch biomass for all spacings tested (0.1 to 1.5 m^2) averaged 67 mt/ha and the mean annual biomass increment 7.4 mt/ha. The "Scotch Plaid" design appears suitable for comparative studies dealing with spacing and rotation.

KEY WORDS: Irrigation, fertilization, growth, allometry, fiber production, multispaced plots, growth equations, biomass distribution.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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BIOMASS PRODUCTION OF 4- TO 9-YEAR-OLD INTENSIVELY CULTURED LARIX EUROLEPIS GROWN IN "SCOTCH PLAID" PLOTS IN WISCONSIN

J. Zavitkovski, *Principal Plant Ecologist,*
Rhinelander, Wisconsin,
Allen L. Lundgren, *Principal Economist,*
St. Paul, Minnesota,
and **Terry F. Strong,** *Forestry Technician,*
Rhinelander, Wisconsin

The objective of this study was to evaluate production potential of *Larix eurolepis,* a hybrid of the European *L. decidua* and the Japanese *L. leptolepis,* under intensive culture and to identify combinations of spacing and rotation that maximize biomass production. Previous studies with *Populus* (Dawson *et al.* 1976, Ek and Dawson 1976, Zavitkovski *et al.* 1976), jack pine (Zavitkovski and Dawson 1978b), and tamarack (Zavitkovski and Dawson 1978a) have indicated that biomass production in stands under intensive culture is significantly higher than under traditional management practices. The studies suggest that wide application of the intensive culture system would help satisfy the increasing demand for fiber in the United States and could provide an alternate energy source or raw materials for synthesis of chemicals that have been traditionally derived from crude oil (Zavitkovski 1979).

The selection of *L. eurolepis* for this study was not accidental. The hybrid has an excellent reputation as a high-volume producer and appears to be well-adapted to a variety of climates in Europe (Ovington 1956, Keiding 1962, 1980). Recently, its suitability for kraft pulping of whole-tree chips has been reported by Isebrands *et al.* (1982).

Because only a limited quantity of the hybrid seed was available for this study, establishment of sizeable, uniformly spaced plantings was not possible. Multiple-spaced plots, such as introduced by Nelder (1962), or "Scotch Plaid" plots proposed by Lundgren (unpublished) were the logical designs for our study. "Scotch Plaid" design was used primarily because of its regular—i.e., square and rectangular—plots. Evaluation of the design and its suitability for forestry research were equally important objectives for our study.

METHODS AND MATERIALS

The plantations were established in July 1972 in the Forestry Sciences Laboratory nursery at Rhinelander, Wisconsin. The seedlings were grown for 8 weeks in a greenhouse in Jiffy 7 containers from seed of *Larix eurolepis* provided by Dr. Helmuth Barner from the Danish State Forestry Tree Improvement Station.

The plantings used a replicated square plot design containing systematic variation in tree spacing developed by Lundgren in 1965 (unpublished) as an alternative to the circular-plot systematic design suggested by Nelder (1962). Lundgren's "Scotch Plaid" design calls for establishing individual plots consisting of rows of trees planted at ever-increasing spacing on both the X and Y axes from a common point of origin (fig. 1a). This provides for testing, using relatively few trees, a wide range of spacing distances and growing-space areas with square to rectangular configurations. The spacing distances are determined by the conditions and objectives of the experiment. The idea behind this design is not only to provide the entire range of spacings within one plot, but also to serve as a living "production surface" for use in field demonstrations.

Multiple replications of plots provide the numbers of trees at each spacing necessary for analysis. The basic replication is a cluster of four adjoining plots with identical spacings, but with different orientations of the expanding rows (fig. 1b). Multiple replication clusters, shown schematically by lines representing rows of trees, give rise to the Scotch Plaid pattern (fig. 1c).

Each plot can be established with single rows for each spacing distance, double rows at each spacing, or other multiple row designs. The multiple row designs provide square spacing for one or more trees at each spacing distance.

For this study, individual plots were established with double rows for each of four spacings at 1-, 2-, 3-, and 4-ft (about 0.3-, 0.6-, 0.9-, and 1.2-m) intervals (fig. 1d). Four replications of the planting were made, consisting of two pairs of individual plots (fig. 1e). In this design, each tree in a plot occupies a unique spacing distance and configuration, but these spacing differences vary systematically and spatially (fig. 1f). This type of plot offers a wide range of square-to-rectangular spacings to test the effect on growth not only of the total growing space available to each tree, but also of the varying spacings between and within rows of trees for a given size of growing space area. The double plots were surrounded by an unplanted area about 3 m (10 ft) wide, which was kept weed-free and was irrigated with the rest of the area.

A high level of soil nutrients was maintained by annual fertilization with N, P, and K at rates of 150, 40, and 40 kg/ha (130, 35, and 35 lbs/acre), respectively. Soil moisture was kept near field capacity by irrigation as required. Weeds were controlled mechanically the first 2 years. In the droughty 1976 summer, irrigation had to be terminated by mid-July and in 1977, by oversight, no fertilizer was applied.

Height of all trees was measured annually from ages 1 to 5, and again at age 9. At ages 4, 5, and 9, diameter at breast height (d.b.h.) was measured. Biomass at ages 4, 5, and 9 was obtained by regression technique (Zavitkovski *et al.* 1974). Briefly, d.b.h. of all trees at age 9 was measured and trees were divided into four d.b.h. classes. Eight trees, two from each d.b.h. class, were harvested from an adjacent planting established for that purpose at a uniform 0.6 x 0.6 m (2 x 2 ft) spacing. Each sample tree was cut at the ground, and its d.b.h. and height were measured to the nearest millimeter and decimeter, respectively.

Branches were removed and, from each 1-m section, one branch, living or dead, was selected for dry-weight determination. Fresh weights of all branches, live and dead, as well as those of the subsample branches were obtained in the field. Stems were cut into 1-m segments and from each segment a 10-cm long disk was cut to determine dry weight. Fresh weights of the whole stem and sample disks were obtained in the field. In the laboratory, bark was removed from each disk and bark and wood were dried at 70°C to equilibrium. Sample branches were dried in the same way. Dry weights were determined to the nearest 0.1 percent of the weight. Dry weights of whole stems and branches were obtained by simple expansion.

Allometric models ($\ln Y = a + b \ln X$) were fitted separately to stem, branch, and whole-tree (aboveground) biomass data. In the equation, $\ln Y$ is the natural logarithm of component dry weight, $\ln X$ is the natural logarithm of d.b.h., and a and b are regression coefficients. Component biomass per hectare was estimated by totaling the dry weights of trees having the same growing space available in all four plots (see next paragraph) and converting the total to a hectare basis.

Each plot was subdivided by drawing imaginary lines midway between each row in each direction (fig. 1f). In this way a growing space was delineated for each tree. The outside border of trees was not used in analyzing the results. Trees falling along the diagonal running from the most dense to the most open spacing occupied square growing spaces, ranging from 1 to 4 ft (0.3 to 1.2 m) on a side, with growing spaces from 1 to 16 ft^2 (about 0.1 to 1.5 m^2). Trees on either side of this diagonal occupied rectangular plots, with mirror-image pairs of identical plots (except for directional orientation) on either side. Trees lying close to the diagonal occupied growing spaces that were only slightly rectangular in shape. Trees farthest from the diagonal had the most extreme rectangular spacing (the most extreme was 1 x 4 feet).

Each plot consisted of 49 subplots (fig. 1f) with 7 square plots and 21 different-paired rectangular plots. This wide variation in dimensions provided 25 different-sized growing space areas within one of these Scotch Plaid plots. Some growing-space areas were represented by only one tree in each replication; for example, only one tree with the 3 x 3 ft spacing occupied a 9.0 ft^2 growing space. Some growing-space areas, such as the 6.0 ft^2 size, were represented by several trees in a replication (two trees at 2 x 3 ft spacing and two at 1½- x 4 ft spacing for the 6.0 ft^2 growing space).

The number of available subplots was reduced because of the absence of a buffer zone around the basic

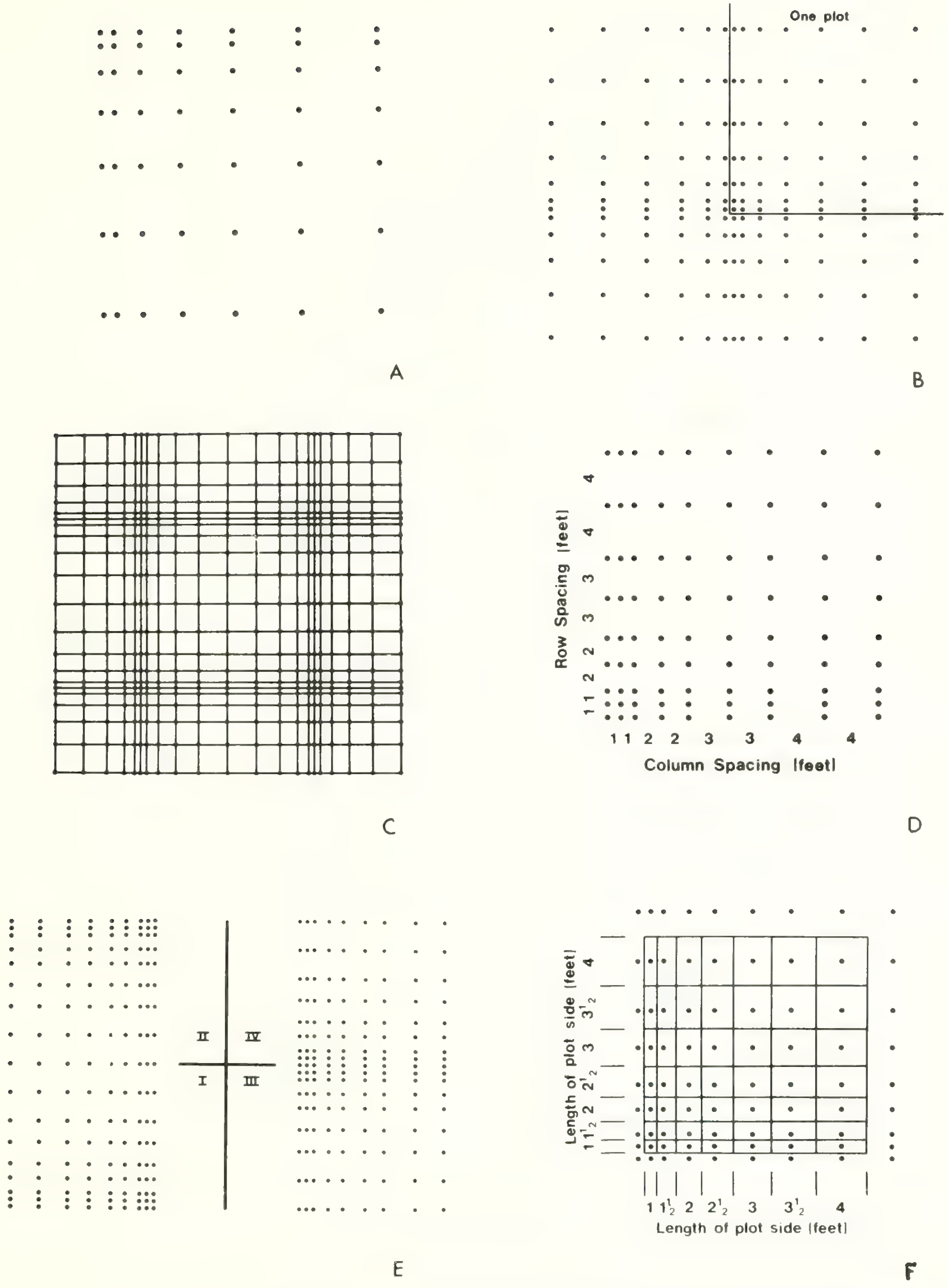

Figure 1.—(A) *A single plot of the Scotch Plaid design, with single rows of systematically increasing spacing. (B) A fully-replicated Scotch Plaid plot design, with 4 adjoining single plots. (C) A schematic diagram, with lines indicating rows of trees, of a solid block of 16 replicated plots forming a Scotch Plaid experimental plot design. (D) A single Scotch Plaid plot used in studying* Larix eurolepis, *with two rows at each spacing from 1 to 4 feet. (E) Four replications of the double-row Scotch Plaid plot design used in studying* Larix eurolepis. *(F) Sub-plot dimensions in feet for those trees used in analyzing* Larix eurolepis *yields, for a single Scotch Plaid plot.*

plots. We decided to avoid the outer row if its d.b.h. was significantly greater than the d.b.h. of the second row, and to avoid the second row if its d.b.h. was greater than that of the third row. Only one row along the 4-ft-wide border had to be avoided, but two rows along the S-N 1-ft-wide border and one along the E-W 1-ft-wide border were avoided. By joining two basic plots side-by-side, a few subplots were gained in both double-plot blocks. Finally, 182 subplots, unequally divided among the 25 different growing spaces, were used in calculating component biomasses. To reduce the variability inherent in estimating component biomasses from a few trees, these 25 different spaces were consolidated into five growing space classes, and biomasses were averaged for each class.

RESULTS AND DISCUSSION

Growing Space and Height and D.b.h. Growth

Height growth during the first 2 years was slow, but thereafter to age 9 heights increased by about 1 m (3.3 ft) per year and averaged 7.5 m (25 ft) at age 9 (fig. 2). The initial effect of the available growing space on height growth was small, and has increased only moderately with time. During the first 5 years, only heights of trees in the dense plot parts were significantly smaller than heights in the rest of the plot. At age 5, the difference between the extremes was about 0.8 m (2.7 ft), only about 25 percent of the average height.

Diameter-growth, however, was strongly affected by growing space (fig. 3, table 1), with average d.b.h. increasing with the available growing space. For example, at age 4 the extreme values were 0.76 and 1.8 cm (a difference of 135 percent) in the 1-2½ and 7½-10 ft² classes, respectively. This relation remained about the same at ages 5 and 9.

Height growth of our intensively cultured *L. eurolepis* was substantially more rapid than that reported in the literature for the same hybrid or other pure *Larix* species grown under traditional silvicultural systems. In Poland (Chodzicki 1967), height of 13-year-old trees of L. *decidua, L. leptolepis,* and *L. eurolepis* averaged 6.8, 6.1, and 7.0 m, respectively. Our trees averaged 7.5 m at age 9. In Czechoslovakia (Machanicek and Prudic 1978), heights of 9-year-old *L. decidua* and *L. eurolepis* averaged 3.8 and 5.2 m, respectively. Although the hybrid grew better than the local source, its height lagged several years behind the intensively cultured hybrid in our

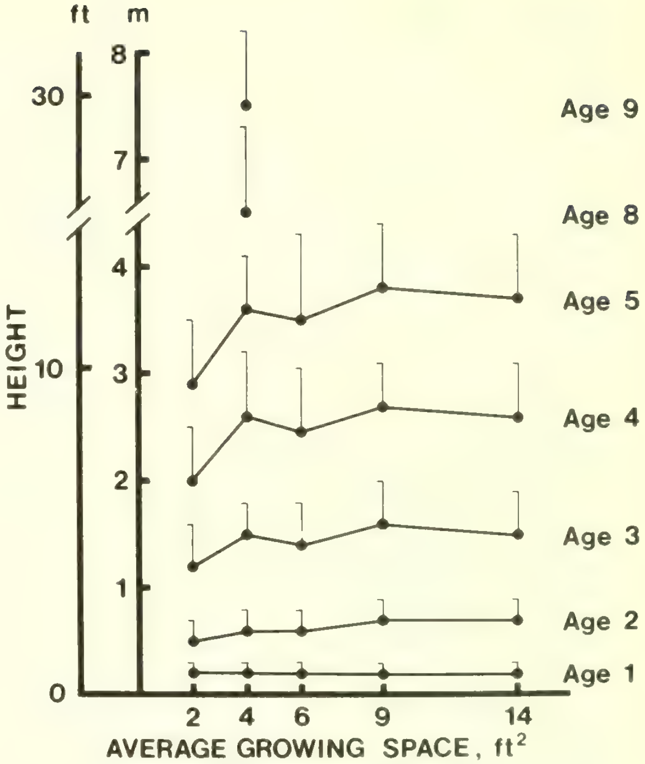

Figure 2.—*Height of 1- to 9-year-old* Larix eurolepis *trees in plots of increasing growing space. Site index of 35 m was calculated according to Laidly (1979) using regression coefficients for tamarack. The height at 8 years is from Isebrands* et al. *(1982). Bars represent one standard deviation.*

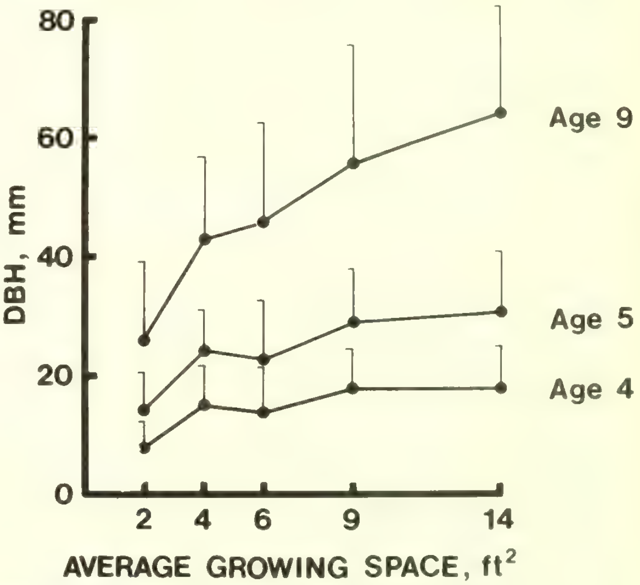

Figure 3.—*Diameter breast height (d.b.h.) of 4-, 5-, and 9-year-old* Larix eurolepis *in plots of increasing growing space. Bars represent one standard deviation.*

Table 1.—*Survival and d.b.h. distribution of* Larix eurolepis *trees*

Growing space (ft^2)	Trees planted	Age 4			Age 5			Age 9		
		Survival	Mean[1]	SD	Survival	Mean[1]	SD	Survival	Mean[1]	SD
	Number	*Percent*	*mm*		*Percent*	*mm*		*Percent*	*mm*	
1-2½	21	81	7.6^{a}	4.6	76	14.1^{a}	6.1	33	25.9^{a}	13.1
3-4½	43	98	15.0^{bc}	6.2	95	24.3^{b}	6.7	79	43.0^{b}	13.4
5-7	45	98	14.0^{b}	7.4	96	22.9^{b}	9.7	73	45.7^{bc}	16.8
7½-10	38	97	17.6^{c}	6.3	97	29.0^{c}	8.7	92	55.8^{cd}	19.9
10½-16	35	100	17.4^{c}	7.3	100	31.0^{c}	10.0	91	64.5^{d}	18.5
All	182	96	15.3	6.6	94	25.4	9.1	77	50.8	17.9

[1] Values with the same letter in each column are not significantly different ($p = 0.05$).

study. Also in several areas in Denmark (Keiding 1980) the height of *L. eurolepis,* although better than heights of *L. decidua* and *L. leptolepis,* was one to several years behind the average height of our trees. Average heights of traditionally cultured hybrid larch in research plots at Rhinelander ranged from 1.3 to 2.3 m at age 5 and from 3.2 to 5.0 m at age 8 (personal communication from Dr. H. Nienstaedt). The intensively cultured hybrid larch averaged 6.5 m (±0.8 m) at age 8 (Isebrands *et al.* 1982).

Whereas heights of our intensively cultured hybrid were consistently better than heights of *Larix* at other locations, the d.b.h. comparisons were more complex, partly because of the strong effect of spacing on d.b.h. growth. In Czechoslovakia (Machanicek and Prudic 1978), the average d.b.h. of 9-year-old *L. eurolepis* in 1 x 1 m plantations was 5.5 cm; our similarly spaced trees (0.9 x 0.9 m or 3 x 3 ft) averaged 5.6 cm. In Denmark (Keiding 1980), 8-year-old plantings spaced 2 x 2 m averaged 6.9 cm at Ulvedal and 8.7 cm at Gurre Vang. Our 9-year-old trees averaged 6.4 cm at the 1.2 x 1.2 m (4 x 4 ft) spacing. A comparison of these data clearly indicates that trees grown under intensive culture are more slender than trees in the traditional silvicultural system. A slenderness index, height in m divided by d.b.h. in cm, can be used to compare the form of forest trees (Rudolf 1951). The index was 0.95 for the hybrid in Cezchoslovakia, about 0.8 for the hybrid in Denmark, and 1.19 for our trees at 1.2 x 1.2 m spacing.

Compared with a traditionally grown tamarack, *L. laricina,* the intensively cultured hybrid was superior in both height and d.b.h. growth. Heights of trees from various tamarack provenances ranged from 2.1 to 3.2 m at age 9 (Jeffers 1975) and from 4.4 to 6.4 m at age 14 (Riemenschneider and Jeffers 1980). The d.b.h. of 14-year-old tamarack ranged from 5.3 to 8.3 cm, and the slenderness index was about 0.8. Seven-year-old, intensively cultured tamarack (Zavitkovski and Dawson 1978a) in 0.6 x 0.6 m (2 x 2 ft) plantings averaged 4.0 m in height and 2.8 cm in d.b.h. Their slenderness index was 1.60, suggesting again that trees under intensive culture are more slender than trees grown under traditional silvicultural systems.

Growing Space and Survival

Survival was positively related to available growing space and negatively to age (table 1). At age 4, for all spacings, survival averaged 96 percent, but was only 81 percent in the densest plot part. By age 9, only 33 percent of the trees in the densest plot parts were still alive. In plots with more growing space, survival exceeded 90 percent. A positive relation between survival and growing space in intensively cultured tamarack was also reported by Zavitkovski and Dawson (1978a). At age 7, in plantings with square spacings of 0.23, 0.30, and 0.61 m, the survival was 48, 64, and 64 percent, respectively.

Destructively Sampled Trees

Biomass distribution among tree components and dry weight as percent of fresh weight were determined for the eight destructively sampled trees harvested in mid-February 1981.

Biomass distribution

On the average, stems accounted for 71 percent and branches for 29 percent of the whole tree (aboveground) dry weight (table 2). There was no evident relation between tree size and biomass distribution. Stem wood accounted for 81 percent and stem bark for 19 percent of the total stem. These percentages varied little over the d.b.h. range of sampled trees (26 to 64 mm). Biomass distribution between stems

Table 2.—*Biomass distribution among tree components in 9-year-old destructively sampled* Larix eurolepis

(In percent)

D.b.h. range (mm)	Trees	Whole tree[1]		Stem	
		Stem	Branches[2]	Wood	Bark
	Number				
26–32	2	65–73	27–35	75–81	19–25
38–45	2	61–77	23–39	79–81	19–21
46–60	2	78–79	21–22	82–83	17–18
62–64	2	63–72	28–37	81–83	17–19
Mean		71	29	81	19

[1] Above ground.
[2] Live and dead without needles.

Table 3.—*Dry weight (as percent of fresh weight) of tree components of 9-year-old destructively samples* Larix eurolepis

D.b.h. range (mm)	Trees	Stem wood	Stem bark	Branches[1]
	Number			
26–32	2	47–50	38–40	62–73
38–45	2	41–45	37–42	59–62
46–60	2	43–44	41–42	52–60
62–64	2	41–42	42–43	50–61
Mean		44	41	60
SD	—	3	2	7

[1] Live and dead without needles.

and branches was similar to that for 7-year-old intensively cultured tamarack (Zavitkovski and Dawson 1978a) spaced at 0.3 x 0.3 m (1 x 1 ft): 70 and 30 percent, respectively. However, in tamarack spaced at 0.6 x 0.6 m (2 x 2 ft), stems made up only 56 percent of whole tree dry weight—considerably less than for the hybrid at this spacing. The percentage of stem wood in the hybrid (81 percent) was moderately higher than that of stem wood in the 7-year-old tamarack, which averaged 76 percent in all three spacings. Ten-year-old *L. eurolepis* in Cezchoslovakia had 62 and 38 percent of the total biomass in stems and branches, respectively.

Dry weight/fresh weight relation

More than one-half of the stem fresh weight was water, with slighly more water in stem bark (59 percent) than in stem wood (56 percent) (table 3). Only 40 percent of the branch weight was water, most likely because both live and dead branches were pooled into one branch component. Branch water content appeared to be positively related with tree size, suggesting that the percentage of live branches on large trees was higher than on small trees. In Great Britain, stems and branches of 23-year-old *L. eurolepis* had 61 percent and 55 percent water, respectively (Ovington 1956).

Growing Space and Biomass Production

Biomass growth model

An allometric (double logarithmic) model based on d.b.h. was fitted to component dry weights of the 9-year-old destructively sampled trees (table 4). Separate equations were calculated for stem wood, stem bark, total stem, live and dead branches, and whole tree (aboveground). The trees were harvested in an area specifically established for that purpose at a uniform 0.6 x 0.6 m (2 x 2 ft) spacing. It is likely that these equations would best fit trees growing under similar spacings and may be less accurate for trees growing in the denser and more open parts of the plantings. In previous studies with tamarack and jack pine (Zavitkovski and Dawson 1978a, 1978b), different allometric equations were prepared for stands spaced 0.3 x 0.3 and 0.6 x 0.6 m (1 x 1 and 2 x 2 ft).

No trees were harvested at ages 4 and 5, thus no specific biomass equations are available for those ages. Instead, biomass equations for the 9-year-old trees were used for the younger stands. We don't know what error this may have introduced, but we believe it to be small. In the previously cited biomass studies on tamarack and jack pine, no significant differences were found between regression coefficients for 6- and 7-year-old trees. In other studies, one set of regressions has been used to estimate biomass of tree components in stands featuring a wide range of ages (Zavitkovski 1971, Hegyi 1972, Zavitkovski and Stevens 1972, MacLean and Wein 1976, Green and Grigal 1978).

Whole tree biomass and mean annual biomass increment (m.a.b.i.)

Whole-tree biomass was most likely highest at the 1-2½ ft^2 spacing for the first 2 or 3 years, but at age 4 the 3-4½ ft^2 spacing became the most productive and remained the most productive through age 9 (table 5). At the same time, the whole-tree biomass of the three upper classes was increasing rapidly. At age 9, all four upper classes had biomasses significantly higher than the first class, which passed its

Table 4.—*Coefficients of allometric regression equations for dry weights of 9-year-old trees of* Larix eurolepis

Tree component	Trees	Regression coefficients[1]				Correction factor[2]
		a	b	R^2	$S_{y \cdot x}$	
	Number					
Whole tree[3]	8	-2.0108	2.1517	0.9707	0.1326	1.0088
Stem wood	8	-2.7292	2.2572	.9745	.1296	1.0084
Stem bark	8	-3.6793	1.9289	.9832	.0895	1.0040
Total stem	8	-2.4152	2.1903	.9787	.1146	1.0066
Live and dead branches	8	-3.1097	2.0409	.8077	.3532	1.0644

[1] For model $Y = a + bX$ where Y is *ln* (dry weight) and X is *ln* (d.b.h.). Dry weights are in kg and d.b.h. in cm.
[2] According to Baskerville (1972).
[3] Above ground without needles.

Table 5.—*Total biomass distribution in relation to growing space of 4- to 9-year-old* Larix eurolepis *stands*

(In metric tonnes/ha dry weight)

Growing space class (ft²)	Age 4			Age 5			Age 9		
	Stem	Branch	Whole	Stem	Branch	Whole	Stem	Branch	Whole
	Mean (SD)								
1-2½	4.3	2.3	6.6	11.2	5.5	16.7	19.6	8.7	28.3
	(2.3)	(1.2)	(3.5)	(5.5)	(2.5)	(8.0)	(13.6)	(6.0)	(19.6)
3-4½	8.1	3.9	12.0	19.6	8.8	28.4	57.9	25.7	83.6
	(2.7)	(1.3)	(4.0)	(3.6)	(1.6)	(5.2)	(8.8)	(5.4)	(14.2)
5-7	4.6	2.2	6.8	12.1	5.5	17.6	40.4	16.5	56.9
	(0.7)	(0.3)	(1.0)	(1.5)	(0.6)	(2.1)	(8.0)	(2.9)	(10.9)
7½-10	4.4	2.1	6.5	12.6	5.6	18.2	52.6	20.9	73.5
	(0.9)	(0.4)	(1.3)	(2.9)	(1.3)	(4.2)	(19.7)	(7.5)	(27.2)
10½-16	3.1	1.4	4.5	10.0	4.4	14.4	43.9	17.2	61.1
	(0.8)	(0.4)	(1.2)	(2.6)	(1.1)	(3.7)	(10.5)	(3.9)	(14.4)
Mean, all	5.1	2.4	7.5	13.5	6.1	19.6	46.7	19.6	67.3
SD	(1.6)	(0.8)	(2.4)	(3.1)	(1.4)	(4.5)	(12.8)	(5.3)	(18.1)

most productive years before age 5. For the four upper classes at age 9, the whole-tree biomass averaged almost 69mt/ha (31 tons/acre) and the mean annual biomass increment about 7.7 mt/ha (3.4 tons/acre) (table 5, fig. 4).

Figure 4 shows the relation between the m.a.b.i. and the available growing space. Linear regressions fitted to the 4- and 5-year-old production data had a negative slope, indicating that the densest spacings produced more biomass than the more open spacings. At age 9, the slope of the regression changed to positive, suggesting that the highest productivity shifted to the wider spacings. This change resulted primarily from two factors: a high mortality in the denser plots (table 1) and an increased biomass growth in the widely spaced parts of the plantings (table 5). It is almost certain that in future years the positive slope of the regression line will become steeper and the highest m.a.b.i. will shift to the more open parts of the plantings. A similar shift in m.a.b.i. with time from dense to more open spacings was also observed in the previously discussed studies on tamarack and jack pine (Zavitkovski and Dawson 1978a, 1978b) and has been seen broadly in other studies dealing with spacing and production (Harms and Langdon 1976, Steinbeck and Brown 1980, Heilman and Peabody 1981).

The whole-tree biomass production of intensively cultured *L. eurolepis* was about 50 percent higher than the best attained in intensively cultured tamarack (Zavitkovski and Dawson 1978a). The highest m.a.b.i. of the 7-year-old tamarack was 5.2 mt/ha, of which 4.0 mt/ha was accounted for by stems. The 9-year-old *L. eurolepis* averaged 7.5 mt/ha (stems 5.2 mt/ha) and the m.a.b.i. is still increasing. Traditionally cultured *L. eurolepis* in Great Britain (Ovington 1956) had a m.a.b.i. of 6.4 mt/ha at age 23, of which stems accounted for 3.3 and branches with needles for 3.1 mt/ha.

Comparison of biomass production in square and rectangular plots

Only 9 out of 81 plots per replication were squares; the remaining 72 plots were rectangles of various shapes (fig. 1f). The question inevitably arises as to which shape provides a better environment for tree

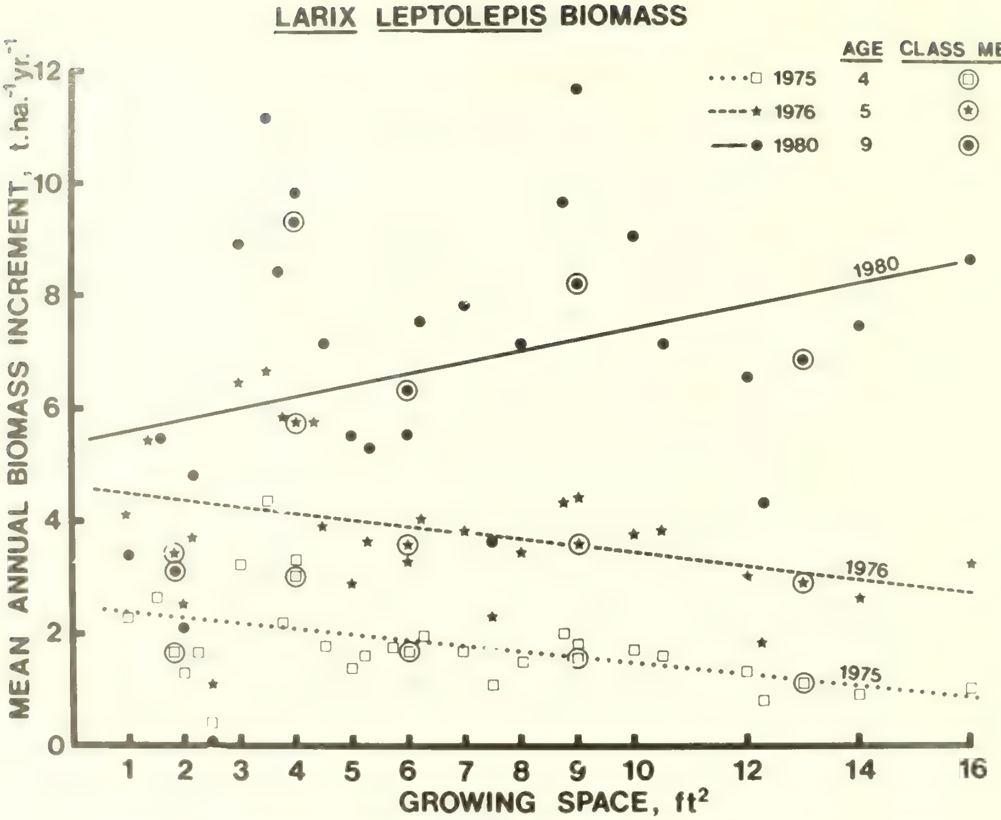

Figure 4.—*Trends of mean annual biomass increment of* Larix eurolepis *as affected by the available growing space at ages 4, 5, and 9 years.*

growth. Our comparison indicated that, on the average, the biomass was about the same in both square and rectangular plots of the same or similar growing space (t = 0.45) (table 6). The nonsignificant difference between shapes may have resulted in part from a rather high variability of the data, but it should be noted that the variability of both data sets was almost the same. Some of the very high values—e.g., equivalent of 110 mt/ha in the 1 x 4 ft plots—may be explained by the proximity of these plots to the planting border. At age 9, disregarding the shape of the plot, the total biomass in plots having growing spaces of 8¾ ft^2 or greater averaged about 30 percent higher than the biomass in plots with smaller growing spaces. The differences, although nonsignificant, are also indicative of the steadily increasing productivity in larger plots as suggested in figure 4.

The Application of the "Scotch Plaid" Design

The first attempt to incorporate various spacings into a single plot was made by Nelder (1962), who also provided the rationale for its use. The original Nelder plots were circular-spoke designs in which tree spacing was controlled by the number of spokes and distance between adjacent arcs. This design, which has been successfully used in many studies, compares favorably with traditional designs (Smith 1978, Lemoine 1980).

Table 6.—*Comparison of total biomass at age 9 in square and rectangular plots of identical or similar area*

Square plots			Rectangular plots		
ft/s2	Size, ft	Biomass, t/ha	ft/s2	Size, ft	Biomass, t/ha
1	1 x 1	30.4	1½	1 x 1½	48.8
2¼	1½ x 1½	43.2	2	1 x 2	19.1
4	2 x 2	51.9	4	1 x 4	110.0
			3¾	1½ x 2½	75.8
			4½	1½ x 3	63.9
6¼	2½ x 2½	67.6	6	2 x 3	68.5
			6	1½ x 4	33.6
9	3 x 3	104.4	8¾	2½ x 3½	86.1
			10	2½ x 4	81.0
12¼	3½ x 3½	38.6	12	3 x 4	58.5
16	4 x 4	77.8	14	3½ x 4	66.4
Mean		59.1			64.7
SD		25.9			25.0
CV%		44			39

Lundgren (unpublished) modified the irregular arc-spoke design of the Nelder plots by incorporating squares and rectangles of increasing size into a basic square-plot design (fig. 1b). By joining four of these basic plots, a complete "Scotch Plaid" design is achieved which, except for its shape, is equivalent to the complete Nelder design. The densest spacings should be located in the center of the "Scotch Plaid" design. Having the more open spacings on the outside will reduce the number of rows needed for the buffer zone, which should be about 1.5 to 1.6 m wide for hybrid poplars (Bowersox and Ward 1976, Zavitkovski 1981) and at least 1 m wide or one row for wider spacings in conifers with a strongly expressed geotropism, such as pines (Sijde 1975, Zavitkovski and Dawson 1978b) and larches (Zavitkovski and Dawson 1978a, this study).

The main advantage of the "Scotch Plaid" design, in comparison to the original Nelder plots, is the regularity of individual subplots and their arrangement in rows. They resemble the traditional plantation designs.

CONCLUSIONS

1. *Larix eurolepis,* a hybrid between *L. decidua* and *L. leptolepis,* proved to be a promising hybrid for production of great quantities of fiber or energy material under short-rotation intensive culture.
2. During the first 9 years, trees grew at an average annual rate of about 0.9 m (3 ft) in height and, except for the densest spacings, showed little variability in height growth in relation to the available growing space. Diameter growth, however, was strongly affected by density. At age 9, the average d.b.h. ranged from 2.3 to 6.4 cm (0.9 to 2.5 in.) in the dense and open plot parts, respectively.
3. At age 9, the total stem-branch biomass in plots with a growing space of 0.3 m^2 (3 ft^2) and greater averaged about 69 mt/ha (31 tons/acre) and the m.a.b.i. was 7.6 mt/ha (3.4 tons/acre). The data indicated that higher biomass yields will be reached at spacings of 1 to 1½ m^2, (i.e., about 9 to 16 ft^2) in the next 5 to 10 years.
4. A shift in biomass production in response to the available growing space occurred between ages 5 and 9. At age 5, the densest plot parts were the most productive but the trend was reversed to more open plots at age 9.
5. The "Scotch Plaid" design appears suitable for this kind of comparative study for which only a limited quantity of genetically improved seed is available.
6. The "Scotch Plaid" design incorporates square and rectangular plots of various sizes. At age 9, no significant difference was found in total biomass between the square and rectangular plots of similar sizes. This suggests that both square and rectangular plots can be used operationally with the same result.

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
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St. Paul, Minnesota 55108
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1983

ANIMAL VECTORS OF EASTERN DWARF MISTLETOE OF BLACK SPRUCE

Michael E. Ostry, *Associate Plant Pathologist,*
Thomas H. Nicholls, *Principal Plant Pathologist,*
St. Paul, Minnesota
and **D. W. French,** *Professor and Head,*
Department of Plant Pathology,
University of Minnesota,
St. Paul, Minnesota

INTRODUCTION AND LITERATURE REVIEW

Eastern dwarf mistletoe, *Arceuthobium pusillum* Peck., is a perennial, parasitic seed plant belonging to the family Viscaceae. A summary of its life cycle appears in figure 1. It is the most serious parasite of black spruce, *Picea mariana* (Mill.) B.S.P., in the Lake States (Minnesota, Wisconsin, and Michigan) (Beckwith and Anderson 1956) and southern Canada (Hawksworth and Wiens, 1972). Dwarf mistletoe, the major cause of mortality in spruce stands, also reduces tree growth, wood quality, and seed production.

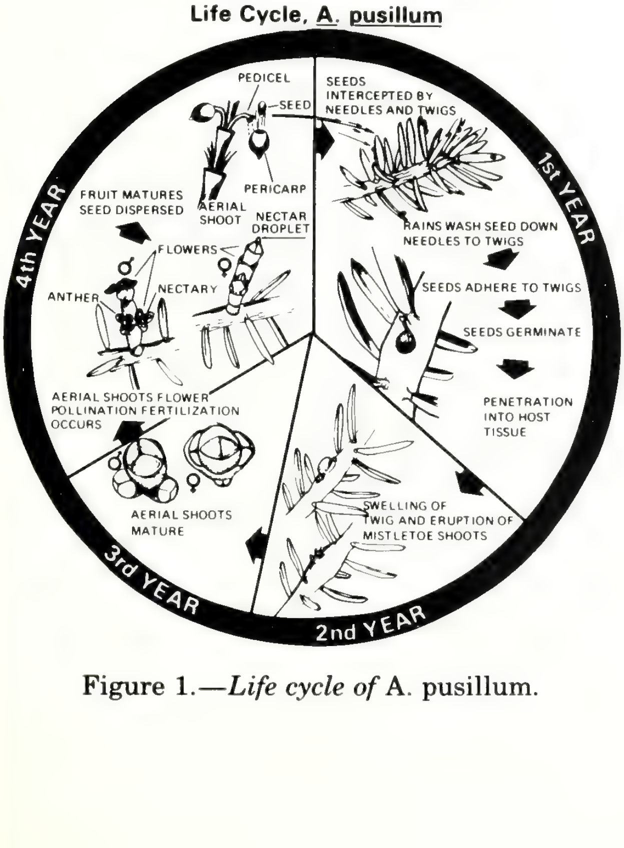
Life Cycle, A. pusillum
PEDICEL
SEED
SEEDS INTERCEPTED BY NEEDLES AND TWIGS
PERICARP
FRUIT MATURES SEED DISPERSED
AERIAL SHOOT
NECTAR DROPLET
RAINS WASH SEED DOWN NEEDLES TO TWIGS
FLOWERS
♂
♀
ANTHER
NECTARY
SEEDS ADHERE TO TWIGS
SEEDS GERMINATE
PENETRATION INTO HOST TISSUE
AERIAL SHOOTS FLOWER POLLINATION FERTILIZATION OCCURS
♂
♀
AERIAL SHOOTS MATURE
SWELLING OF TWIG AND ERUPTION OF MISTLETOE SHOOTS
1st YEAR
2nd YEAR
3rd YEAR
4th YEAR

Figure 1.—*Life cycle of* A. pusillum.

Black spruce occupies 890,340 ha in the Lake States. Surveys of black spruce stands on National Forests in the Lake States indicated that 15 percent of the stands were infected with dwarf mistletoe (Anderson and Mosher 1977). In Michigan, 17 percent of the black spruce stands in the Upper Peninsula (Anderson and Mosher 1976) and 1 percent in the Lower Peninsula were infected with dwarf mistletoe (Mathiasen 1979).

A. pusillum is found to a lesser extent on white spruce, *Picea glauca* (Moench) Voss, in the Lake States, although this species is commonly attacked along the Maine coast (Hawksworth and Wiens 1972) and in Manitoba (French *et al.* 1981). The mistletoe is occasionally found on red spruce, *P. rubens* Sarg. (Hawksworth and Shigo 1980), and eastern larch, *Larix laricina* (Du Roi) K. Koch (Tainter and French 1967; Kliejunas 1969).

Rare hosts include blue spruce, *P. pungens* Engelm. (U.S. Department of Agriculture 1960); jack pine, *Pinus banksiana* Lamb. (Laut 1967); (Baker *et al.* 1978), red pine, *P. resinosa* Ait. (Kuijt 1955); and eastern white pine, *P. strobus* L. (House 1935).

Eastern dwarf mistletoe is endemic in North America and, once established, will persist in the stand for as long as the host is present. The most apparent symptom of the disease is the stimulated growth and malformation of infected branches. These bushy masses of branches and twigs are called "witches' brooms" and may grow to 1 to 3 meters in diameter (Anderson and Kaufert 1959). Swelling, positive phototropic response of infected branches, and spike tops are other disease symptoms (Ostry and Nicholls 1976) (fig. 2).

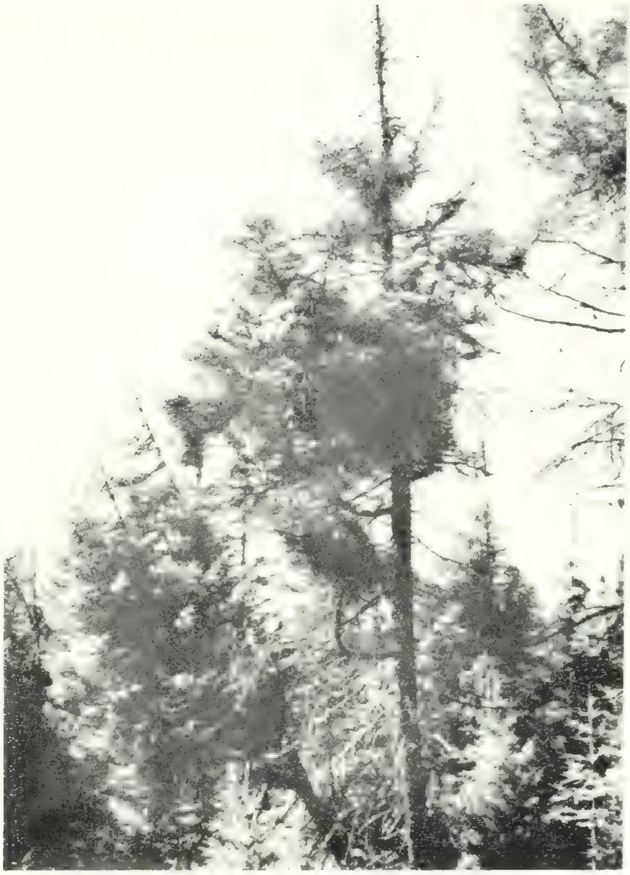

Figure 2.—*Mistletoe-infected black spruce with typical symptoms.*

Most dwarf mistletoe seeds are disseminated by being explosively ejected from the fruit (fig. 3). These seeds can reach as far as 15.24 m (Hinds *et al.* 1963). Discharged seeds of *A. pusillum* were found to travel a mean horizontal distance of 1.65 m and a maximum of 13.7 m (Hudler and French 1976). Recently, a study indicated that *A. pusillum* seeds could be discharged as far as 16.5 m (Baker 1981). The sticky seeds adhere to objects in their flight path. In dense, even-age stands, seeds are intercepted by trees or branches adjacent to the infected tree, reducing dispersal distance.

Establishment of dwarf mistletoe infections beyond the range of their explosive fruits suggests the involvement of vectors. *A. pusillum* is present on islands off the Maine coast and in Lake Michigan, 32 or more km across water from the nearest known infection (Hawksworth and Wiens 1972). Single, isolated infected trees found in a recent mistletoe survey in Michigan were attributed to possible instances of bird-disseminated mistletoe seed (Mathiasen 1979).

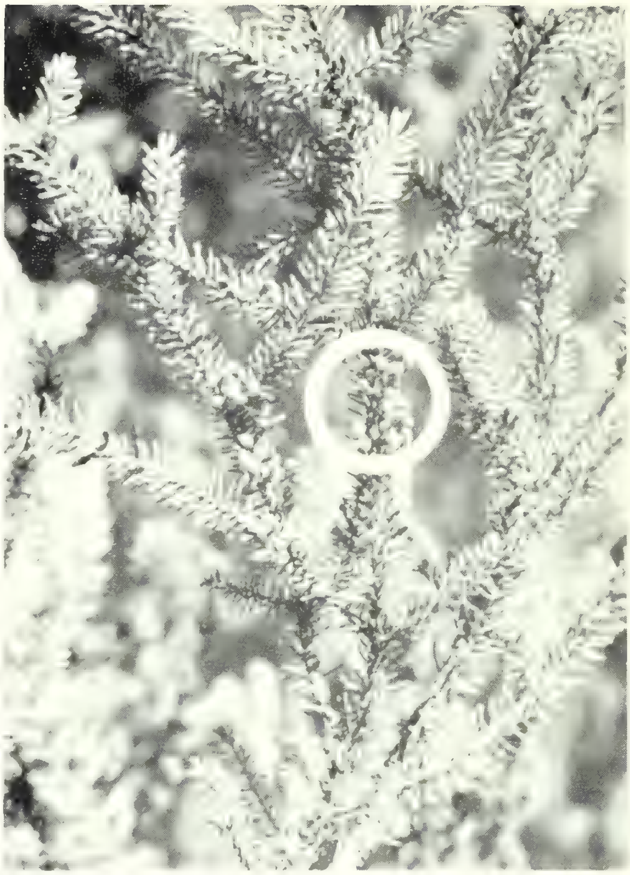

Figure 3.—*Pistillate fruits of eastern dwarf mistletoe before seed dispersal.*

Anderson (1949) observed that gray jays (*Perisoreus canadensis),* chickadees (*Parus* spp.), and nuthatches (*Sitta* spp.) may have been responsible for establishing numerous isolated infections of *A. pusillum* in black spruce stands (fig. 4). He speculated that seeds could adhere to birds searching for food in infected trees and these seeds could later be transferred to healthy trees in some manner. Hudler *et al.* (1974) found *A. pusillum* seeds in feathers of gray jays, a robin (*Turdus migratorius),* and a red squirrel (*Tamiasciurus hudsonicus)* in a black spruce stand infected with *A. pusillum*. They concluded that the gray jay or any animal that frequents dwarf mistletoe brooms was a potential vector for the parasite. Gray jays were found nesting in a black spruce witches' broom caused by *A. pusillum* (Warren 1899).

Radio telemetry is a useful technique for obtaining and transmitting information from a living organism and its environment to an observer some distance away. Most early telemetric studies involved large animals such as deer, raccoons, foxes,

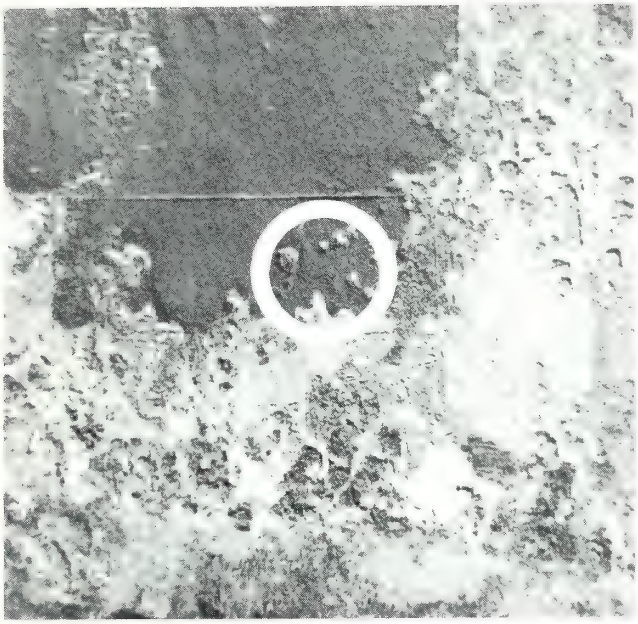

Figure 4.—*Aerial photograph of mistletoe infection center and associated satellite infection centers.*

geese, and ducks that could carry the relatively heavy radio transmitters of that time. By the late 1960's technological improvements resulted in transmitters that were smaller, stronger, lighter, and longer-lived. These new transmitters made it possible to radio-track smaller animals and study birds without significantly affecting their natural behavior (Nicholls and Warner 1966).

Few small birds have been radio-tracked. Starlings (*Sturnus vulgaris)* (Bray *et al.* 1972, 1975), *Hylocichla* thrushes (Cochran *et al.* 1967), robins (Graber and Wunderle 1966), woodcocks *(Philohela minor)* (Godfrey 1970), red-cockaded woodpeckers (*Dendrocopos borealis)* (Jackson *et al.* 1977), and cowbirds (*Molothrus ater)* have been tracked. None of these studies, however, were concerned with birds as vectors of pathogens.

OBJECTIVE

The primary objective of this study was to determine the role of animals in the long-distance dissemination of eastern dwarf mistletoe seed. Long-distance dissemination, as defined in this study, is the movement of *Arceuthobium* seeds more than 16.5 m, the maximum recorded distance. A secondary objective was to adapt and refine radio telemetry equipment and techniques for use in studying the movements and behavior of potential avian vectors of dwarf mistletoe.

MATERIALS AND METHODS

Study Area

Field work was done on the Fond du Lac State Forest (46° 40′ N. lat. and 92° 44′ E. long.) near Cloquet in Carlton County, Minnesota. The forest is near the southern range of commercial black spruce in Minnesota. The lowland organic soil site was occupied by an even-aged stand of black spruce averaging 120 years of age and 12 m in height. Understory consisted predominantly of sphagnum moss (*Sphagnum* spp.), labrador tea (*Ledum groenlandicum* Oeder), and cranberry (*Vaccinium* spp.).

Within the immediate study area, which was approximately 2 km^2 in size, were one large infection center, 0.87 ha adjacent to Spirit Lake, and several smaller satellite infection centers scattered among otherwise healthy black spruce (fig. 5).

The area was divided into nine sections by using natural breaks in the stand and arbitrarily running compass lines and marking trees with plastic flagging. Each section of the stand was visually evaluated for incidence and severity of mistletoe infection.

Characterization of Infection Centers

Fixed-wing aircraft were used on two occasions by Northeastern Area State and Private Forestry, USDA

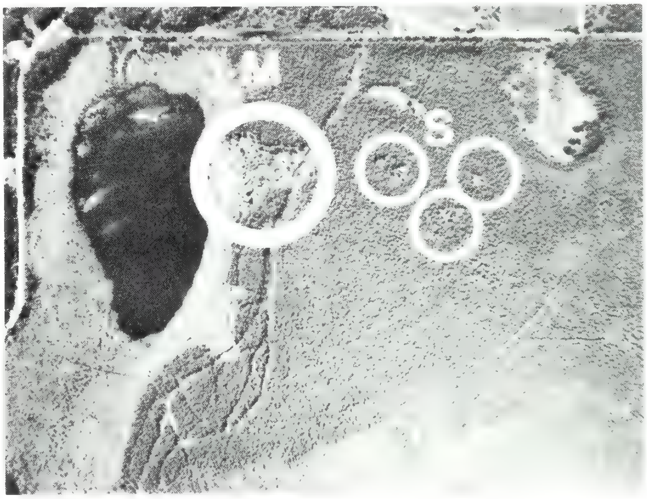

Figure 5.—*Vertical photograph of Spirit Lake study area. (M = Main infection center, S = Satellite infection center).*

Forest Service, to provide the aerial photography of the study area. In April of 1974, 35 mm and 70 mm hand-held cameras provided oblique photos. Black and white, color, and color infrared films were used. In August 1975, vertical 23 x 23 cm infrared transparencies were taken at a scale of 1:6000. In addition, existing 23 x 23 cm black and white photography at a scale of 1:15840 was examined.

All satellite infection centers within the study area were located on aerial photographs and examined on the ground to determine their size and distance from other infection centers. A satellite infection center was defined as one that could not have originated from explosive mistletoe seed dispersal. Size of each center and age of advanced reproduction, if any, were used to determine the relative age of satellite centers in relation to the main infection center.

Trapping, Banding, and Color-Marking

Birds and squirrels were trapped in mistletoe infection centers during seed dispersal each September from 1974-1976 to determine if they carried mistletoe seeds on their bodies. Birds were trapped with nylon mist nets in mesh sizes 30, 36, and 61 mm^2 (fig. 6). Nets were 2.6 m tall and 6 and 12 m long. They were positioned to intercept birds in their observed flight paths. Occasionally, suet was hung in nearby trees to attract birds to nets. During the 3 years of the study a total of 2,916 meters of net were used for a total of 248 trapping hours. Nets were placed throughout the study area including the main infection center, satellite infection centers, and healthy portions of the stand to obtain data on bird populations and movements.

In addition, live traps baited with cracked corn, sunflower seeds, suet, and spruce cones were used to trap squirrels and gray jays. Traps were 20.3 x 20.3 x 66 cm in size and had two compartments. They were made of 16 ga. welded wire cloth with 1.27 x 2.54 cm mesh. Traps were placed in trees and on the ground in infected and healthy areas of the stand. All animals captured were examined for the number and location of mistletoe seeds adhering to their bodies. Seeds were removed and then squirrels and most birds were immediately released. Some birds were held in traps so that fecal material could be collected and examined for mistletoe seeds.

Birds were banded with U.S. Fish & Wildlife Service numbered leg bands (fig. 7). All year-round resident birds such as the chickadees and gray jays also were fitted with colored plastic leg bands for easier identification of individual birds. In addition, some gray jays were color-marked by carefully applying a light coat of fluorescent spray paint to their tail and primary wing feathers (fig. 8). Individual birds and family groups were identified by using various color combinations. Paint was also used to color-mark red squirrels.

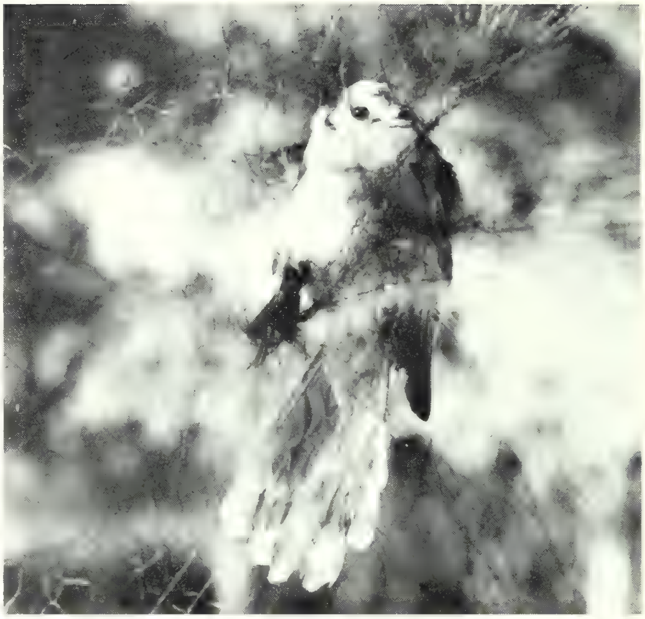

Figure 6.—*Gray jay trapped in mist net.*

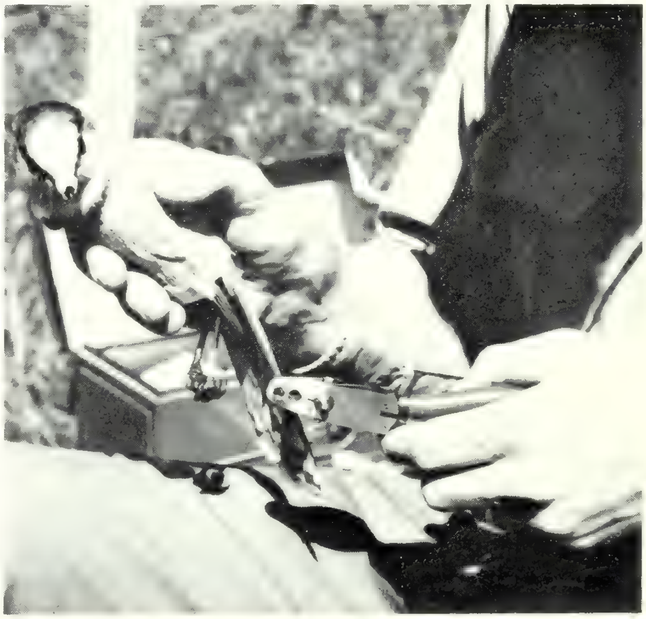

Figure 7.—*Banded gray jay.*

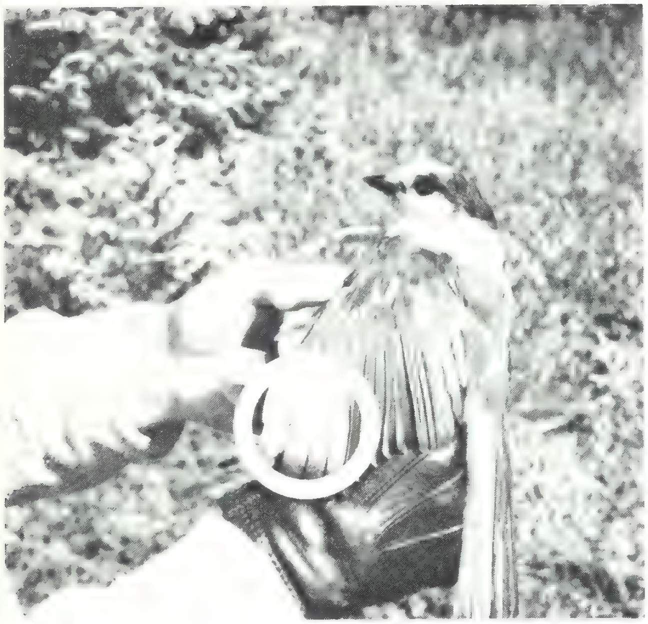

Figure 8.—*Color-marked gray jay.*

Telemetry

Preliminary studies to determine the feasibility of attaching radio transmitters to birds approximately the size of gray jays were done using blue jays (*Cyanocitta cristata*) and radio transmitter mock-ups. We tried to attach radio transmitters directly to the birds' clipped back feathers with eyelash cement or surgical glue. A tail clip mount was also tried (Bray and Corner 1972). In addition, two types of harnesses were designed on which radio transmitters were attached. Both types of harnesses were made from latex penrose tubing, a surgical drainage tubing, 30.5 cm long with a 1.6 cm inside diameter. After a bird had been fitted with a mock-up radio transmitter, it was released into an enclosure for observation. Notes were taken on how the radio transmitter affected the bird's ability to move freely.

Radio transmitters were designed to be light weight and still achieve a rated life of about 20 days. Radio transmitter packages weighed 3.4 to 5 g, about 4 to 6 percent of the average body weight of gray jays. Each radio transmitter had its own frequency within the range 150.700 to 151.275 MHZ. Antenna lengths ranged from 19.1 to 24.1 cm.

In 1973 one radio transmitter was cemented onto two straps made from the latex tubing. This harness and radio transmitter were placed on a gray jay's back and the four strap ends were sewn together with thread across the breast of the bird. Remaining radio transmitters were attached to gray jays by using a modified harness patterned after the American woodcock back-pack harness described by Godfrey (1970) (fig. 9). The harness was reduced to ensure a proper fit on the smaller gray jay, and a piece of coarse cotton fabric was cemented between the harness and the bottom of the radio transmitter. This harness design and radio attachment was used in all subsequent work in 1974 and 1975 (Ostry and Nicholls 1979b). All gray jays were examined and weighed before radios were attached and after birds were recaptured to determine if there were injuries or weight loss because of the radio transmitter and harness.

Radio receivers and hand-held yagi antennas were used in 1973 to track birds to determine general patterns of their movements. In 1974 and 1975, three receiver stations were set up 0.4 km apart within the study area to permit radio-tracking by the triangulation method using degree bearings obtained from each station. A yagi antenna was mounted on top of an Osborne Firefinder at each station (fig. 10). Aerial photos of the study area were used as map bases on the firefinders. The receiving stations' locations on the photos were centered on the firefinders, and the photos were divided into a square grid with a scale of 2.54 cm equaling 83.8 m (fig. 11). Walkie-talkies enabled observers to record simultaneous fixes on radio signals. Resulting azimuth readings were used to locate the position of each individual bird being tracked. Radio fixes were then plotted on outline maps of the study area. These data represented the movement of individual birds over a specific period of time.

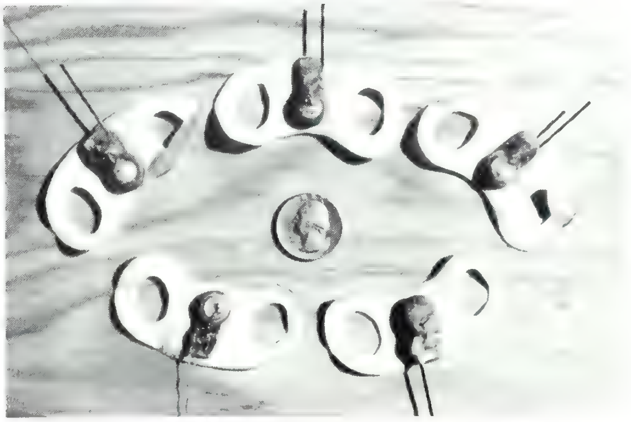

Figure 9.—*Gray jay radio transmitter packages.*

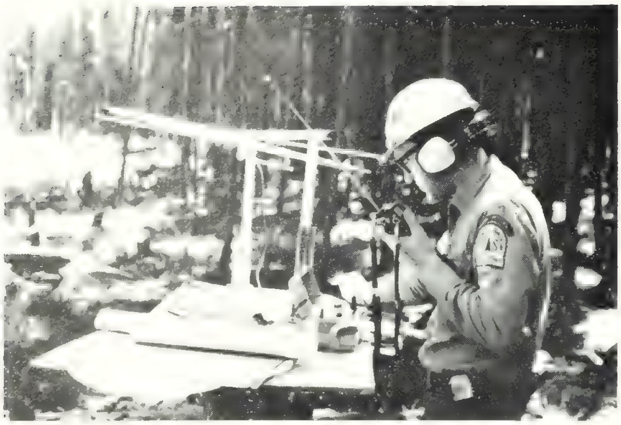

Figure 10.—*Radio telemetry receiving station.*

Animal Behavior

Field Observations

In the 3 years of this study, a total of 49 days were spent observing animal activities, from 0700 to 1700 hrs each day. Animals within infected and healthy trees were carefully observed, especially with reference to the portions of the trees they used and the amount of time they spent in infection centers. The animals were observed by using 7 x 35 binoculars and a 20X spotting scope. Bathing, preening, and feeding behavior of birds received particular attention. Nesting habits of the red squirrel and various bird species known to nest in the study area were also noted.

Captive Bird Studies

It was difficult to observe in the field whether birds ate mistletoe seeds and whether seeds adhering to their bodies were removed through their hygienic habits or other activities and deposited onto trees. These difficulties were overcome by studying birds in captivity. An enclosure with a one-way glass viewing panel was used that allowed us to observe the birds without disturbing them.

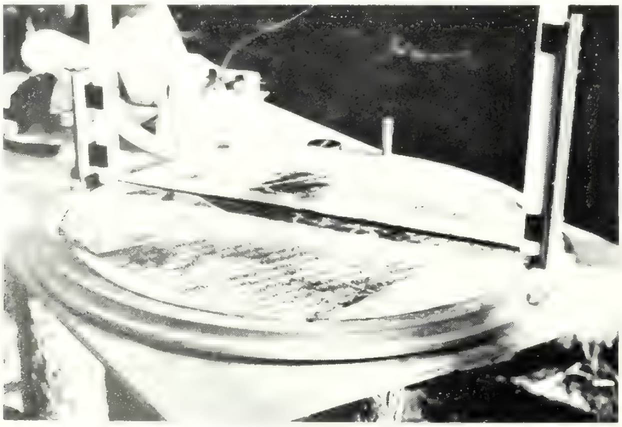

Figure 11.—*Radio telemetry receiving station with map grid used to plot bird locations.*

Food Preference Study

In the laboratory enclosure, dark-eyed juncos (*Junco hyemalis)* and black-capped chickadees (*Parus atricapillus)* were provided with several 0.6 m high potted black spruce trees to serve as perches. Artificial light provided was timed to existing day length.

Birds were given cracked corn, sunflower seeds, millet, mistletoe seeds, shoots, and entire mistletoe berries. At other times only mistletoe seeds were provided. A known number of mistletoe seeds were put into the enclosure and the number missing was recorded at various time intervals. Mistletoe seeds offered to the birds included those enclosed by the exocarp, ones that had been expelled and were still sticky (fig. 12), and those that were washed clean of viscin. Birds were occasionally force-fed mistletoe seeds to determine if the seeds would pass through their digestive systems intact and viable.

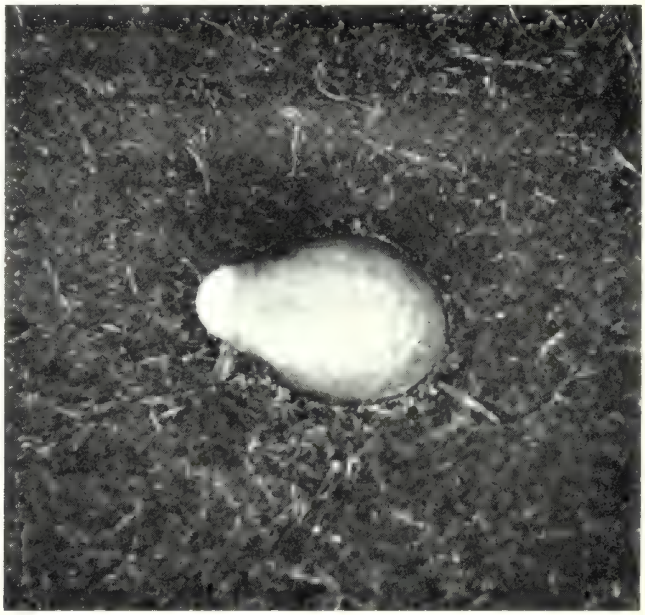

Figure 12.—*Mistletoe seed immediately after being discharged from berry. Note the viscous coating that causes the seed to adhere to objects it strikes (about 30 x).*

Seed Movement Study

To determine if ejected seeds lodged on trees could be moved to other trees by birds, a known number of moistened mistletoe seeds were placed on several branches of two potted trees and allowed to dry. Another tree without seeds on it was placed in the enclosure between these trees. Birds were released into the enclosure without other food to determine if they would search for and eat this seed and in doing so, move seed to adjacent trees.

Bird Preening Study

To observe preening habits of birds and the fate of mistletoe seeds adhering to a bird's body, we placed seeds moistened with a fluorescent brightener on the birds in positions similar to where seeds were found on birds in the field. Seeds removed by the birds could easily be found by using a D.C.-powered black light. Periodically the birds were removed from the enclosure and they, the interior of the enclosure, and the perch trees were closely examined for seeds. The number and position of all seeds were noted and the birds were released back into the enclosure. Birds were observed periodically over several days until all seeds were gone from their bodies. At other times a bird with seeds was released into the enclosure several times a day, and the exact times it took the bird to remove the seeds were recorded.

RESULTS

Characterization of Infection Centers

In addition to the main infection center, 12 satellite infection centers were found within the study area (fig. 13). They ranged in size from a single infected tree, not visible on aerial photographs, to a center 30 by 52 m containing more than 100 infected trees. Centers were randomly located throughout the area and ranged from 72 to 736 m away from the main infection center and from 30 to 250 m away from the nearest other satellite infection center (table 1).

We could not detect small satellite infection centers, but could locate large infection centers using the small-scale and oblique photography. Vertical infrared photography taken in August at a scale of 1:6000 proved best for locating small satellite infection centers. This photography, in contrast to the black and white, allowed distinction between conifers and herbaceous understory visible in infection centers with open canopies.

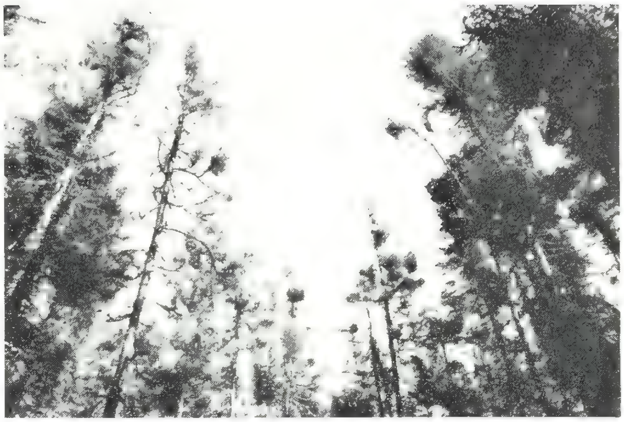

Figure 13.—*View of a satellite infection center showing the opening created in the canopy caused by the death of heavily infected trees. These openings and associated infected trees attract foraging birds.*

Of 13 areas originally marked on the photos as possible satellite infection centers, one was an area with several wind-thrown trees. This area resembled an infection center on the photos in all respects except it lacked one characteristic of mistletoe infection centers—standing dead trees.

Table 1.—*Characteristics of satellite infection centers*

Center number	Area	Infected trees	Distance and direction from main infection center	Distance from nearest source of inoculum
	m²	*Number*	------------*m*-----------	
1	272	47	250 W	250
2	2	1[1]	72 E	72
3	21	3	191 NE	147
4	1,525	[2]	103 N	59
5	1,362	[2]	206 NW	30
6	326	94	221 N	30
7	1,092	[2]	398 N	162
8	214	31	545 NW	44
9	1,033	[2]	736 NE	74
10	1,308	[2]	707 N	74
11	540	[2]	663 N	30
12	1,071	[2]	545 NE	30

[1] Staminate infection.
[2] Over 100 infected trees.

Trapping, Banding, and Color-Marking

A total of 250 birds and squirrels (not including recaptures) representing 45 species were captured during this study (table 2).

Table 2.—*Birds and mammals sighted or captured in or near a mistletoe-infected black spruce stand in September 1973-78*

	Number captured[1]					
Species	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**
Ruffed grouse (*Bonasa umbellus)*						
Marsh hawk (*Circus cyaneus*)		1				
Sharp-shinned hawk (*Accipiter striatus*)		1	2	1		
Red-tailed hawk (*Bueto jamaicensis*)						
Broad-winged hawk (*Bueto platypterus*)						
Rough-legged hawk (*Bueto lagopus)*						
American-Kestral (*Falco sparverius*)						
Hairy woodpecker (*Dendrocopos villosus*)	1	2				
Downy woodpecker (*Dendrocopos pubescens*)	1					
Pileated woodpecker (*Dryocopus pileatus*)				1		
Black-backed three-toed woodpecker (*Picoides arcticus*)						
Northern Three-toed woodpecker (*Picoides tridactylus)*						
Yellow-bellied sapsucker (*Sphyrapicus varius*)						
Common flicker (*Colaptes auratus*)		2	1			1
Traill's flycatcher (*Empidonax traillii*)			2			
Blue jay (*Cyanocitta cristata*)	5	3	1	3		
Gray jay (*Perisoreus canadensis*)	7	12	4	2	2	4
White-winged crossbill (*Loxia leucoptera*)						
American goldfinch (*Spinus tristis*)						
White-throated sparrow (*Zonotrichia albicollis*)			2	1		
Swamp sparrow (*Melospiza georgiana*)			1			
Dark-eyed Junco (*Junco hyemalis*)		5	4	1		
Solitary Vireo (*Vireo solitarius*)						
Tennessee Warbler (*Vermivora peregrina*)			6			
Yellow Warbler (*Dendroica petechia*)			1			
Yellow-rumped Warbler (*Dendroica coronata*)	6	34	37			
Magnolia Warbler (*Dendroica magnolia*)			1			
Blackburnian Warbler (*Dendroica fusca*)			2			
Pine Warbler (*Dendroica pinus*)		1	1			
Yellow Palm Warbler (*Dendroica palmarum*)			12	1		
Connecticut Warbler (*Oporornis agilis*)			8			
Wilson's Warbler *(Wilsonia pusilla*)			1			
House Wren (*Troglodytes aedon*)						
Brown Creeper (*Certhia familiaris*)	1	1	1			
Red-breasted Nuthatch (*Sitta canadensis*)		1				
Black-capped Chickadee (*Parus atricapillus*)						1
Boreal Chickadee (*Parus hudsonicus*)	4	8	8			
Golden-crowned Kinglet (*Regulus satrapa*)		1	3			
Ruby-crowned Kinglet (*Regulus calendula*)		2	2			
Swainson's Thrush (*Hylocichla ustulata*)			3			
Hermit Thrush (*Hylocichla guttata*)	2	1	2			
Robin (*Turdus migratorius)*						
Northern Flying Squirrel (*Glaucomys sabrinus*)		6				
Red Squirrel (*Tamiasciurus hudsonicus*)	3	3	6	4		2
Least Weasel (*Mustela rixosa*)				1		
TOTALS	30	84	111	15	2	8

[1] Does not include recaptures of previously banded birds.

In the 2 years of trapping during seed dispersal period, we found that 28 animals of seven species had a total of 45 seeds on their bodies (tables 3-4). In 1973, presumably due to a sudden and severe

Table 3.—*Number and location of mistletoe seeds on individual animals trapped during September, 1974*

Date	Animal species	Seeds	Seed location
		Number	
9/17	Gray jay	1	Top of left wing—between 10 and 11 primary feathers
9/18	Red squirrel	1	Right rear leg
9/20	Flying squirrel	2	Right rear leg
		2	Left front leg
		1	Belly
		1	Left rear leg
		1	Right front leg
		1	Left cheek
		1	Right side of rump
	Yellow-rumped warbler	1	Underside of right wing
	Yellow-rumped warbler	1	Belly
	Dark-eyed junco	1	Left cheek
9/22	Gray jay	1	Right cheek
	Dark-eyed junco	1	Underside of left wing
		2	Belly
9/23	Flying squirrel	1	Tail
9/25	Gray jay	1	Top of left wing
TOTALS	10 animals	20	

frost, most seeds either discharged or aborted one night, and no animals were captured with seeds during this short peak period of seed dispersal. Peak seed dispersal was when seeds were being forcibly discharged from most brooms. Only a few brooms discharged seeds during early and late dispersal periods. Post dispersal was after all brooms had ceased discharging seeds. During peak seed dispersal in 1974, we found seeds on 12 percent (N = 58) of the birds and squirrels we captured (fig. 14). One dark-eyed junco with three seeds on its body was captured 142 m from the nearest infection center (fig. 15).

In 1975 we found seeds on 20 percent (N = 64) of the animals we captured (fig. 16). Several animals captured in 1974 and 1975 had more than one seed adhering to their bodies (tables 3-4). All seeds found on animals appeared to be viable. The viscin on most seeds was still sticky. Some seeds were, however, dried and deeply embedded in the birds' feathers.

In 1974, most birds captured with seeds were warblers (*Dendroica* spp.) that were migrating through the area (fig. 17). In 1975, however, birds most often captured with seeds were gray jays (fig. 18). Red and Northern flying squirrels (*Glaucomys sabrinus*) (fig. 19) also were captured with seeds on their bodies.

Table 4.—*Number and location of mistletoe seeds on individual animals trapped during September, 1975*

Date	Animal species	Seeds	Seed location
		Number	
9/9	Gray jay	1	Underside of left wing
9/10	Yellow-rumped warbler	1	Back
9/10	Gray jay	1	Left side of neck
9/10	Gray jay	1	Right side of breast
		1	Under tail coverts
9/10	Gray jay	1	Underside of right wing
		1	Lower breast
9/11	Gray jay	1	Crown
		1	Underside of left wing
9/11	Red squirrel	1	Left rear leg
9/11	Gray jay	1	Upper right leg
9/11	Gray jay	2	Under tail coverts
9/11	Palm warbler	1	Chin
9/11	Gray jay	1	Belly
9/12	Gray jay	1	Left flank
9/12	Gray jay	1	Underside of left wing
9/13	Gray jay	1	Breast
9/13	Gray jay	1	Upper breast
		1	Left flank
9/14	Gray jay	1	Left side of neck
9/16	Yellow warbler	1	Right flank
		1	Left flank
		1	Under tail coverts
9/16	Gray jay	1	Breast
TOTALS	18 animals	25	

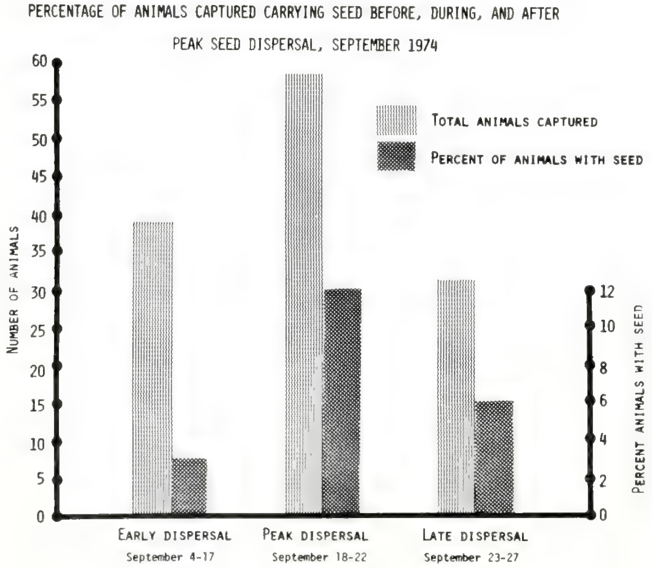

Figure 14.—*Percentage of animals captured carrying seed before, during, and after peak seed dispersal, September 1974.*

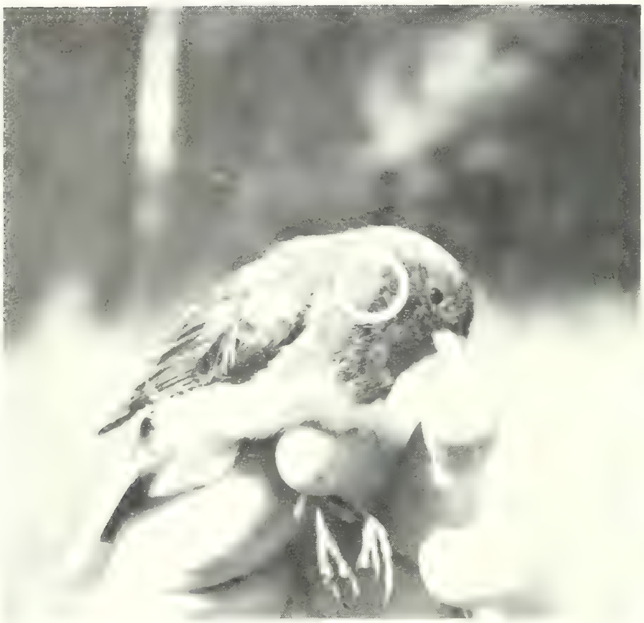

Figure 15.—*Dark-eyed junco with 3 seeds on its body captured 142 m from the nearest mistletoe infection. NOTE one seed adhering to neck.*

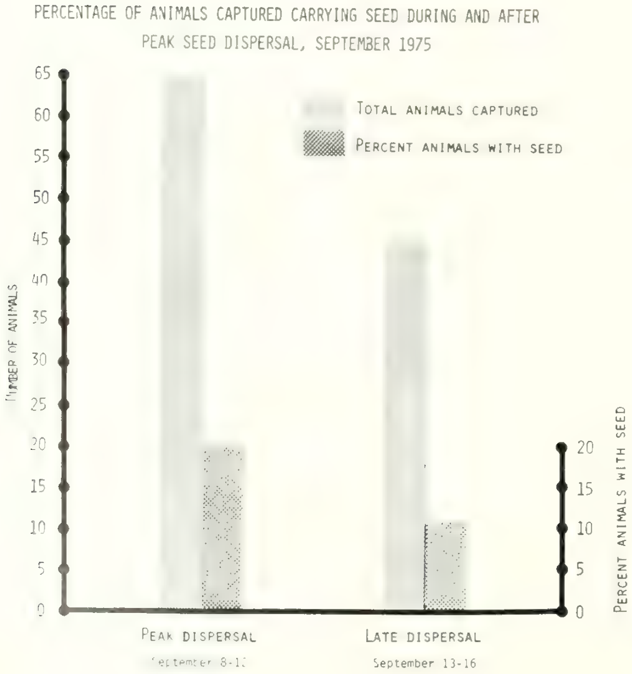

Figure 16.—*Percentage of animals captured carrying seed during and after peak seed dispersal, September 1975.*

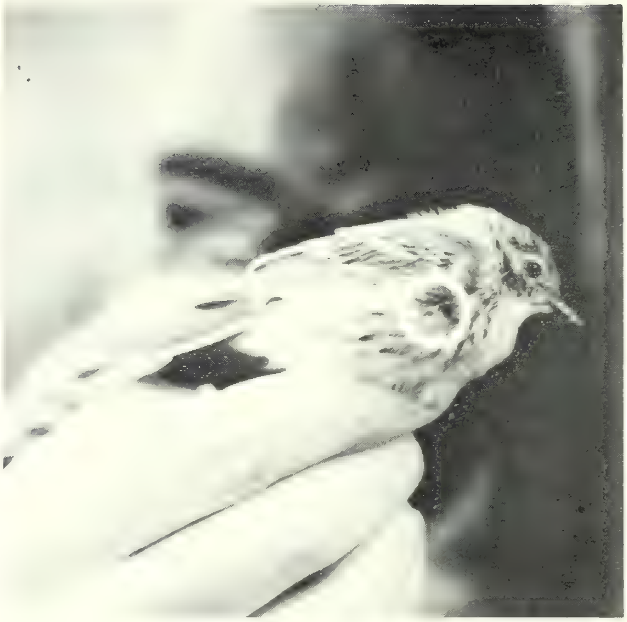

Figure 17.—*Yellow-rumped warbler with seed adhering to its side captured in infection center.*

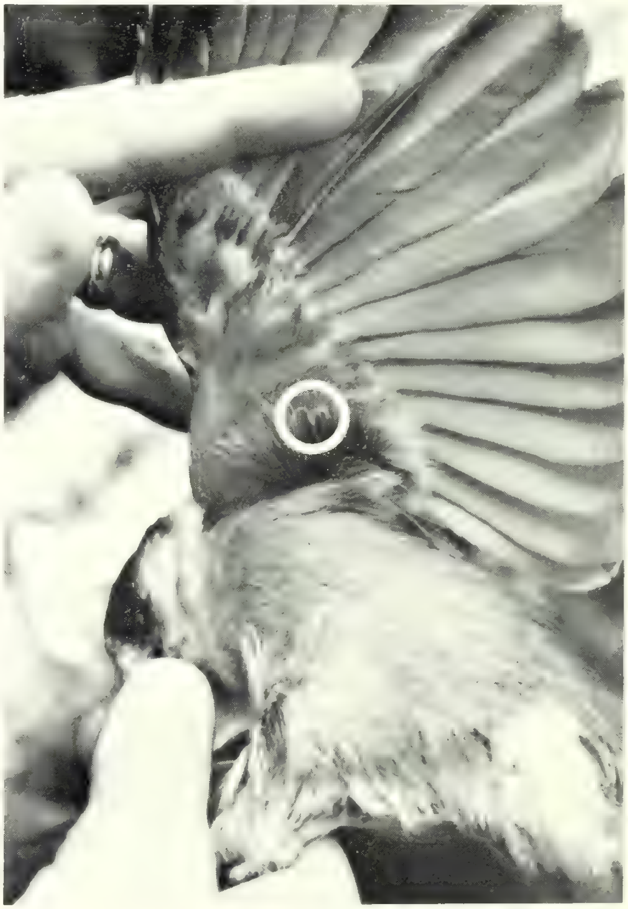

Figure 18.—*Gray jay with a seed adhering to down feathers under its wing.*

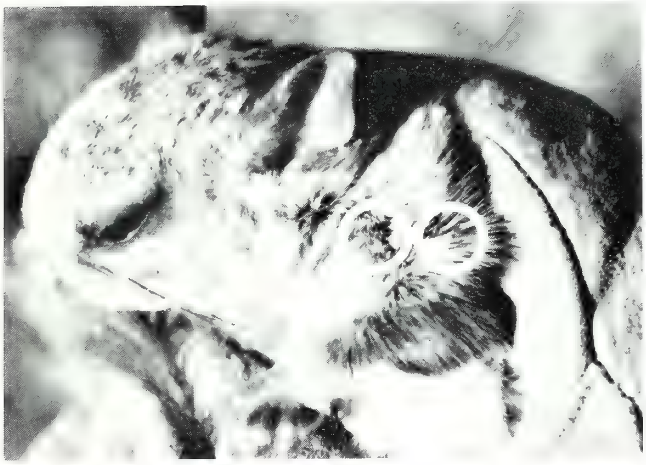

Figure 19.—*Flying squirrel captured in infection center with nine seeds adhering to its body. Three seeds are visible in this photo.*

During 1973-1975, 19 gray jays were banded within the study area. In addition, four gray jays banded in 1972 were recaptured and color leg bands were added. These 23 gray jays were recaptured within the study area a total of 126 times during the 3-year study.

Banding and color-marking techniques greatly enhanced identification of individuals and family groups of gray jays. These birds frequently visited infection centers and healthy areas of the stand, indicating that their home range included all or most of the study area.

Three family groups of gray jays were active within the main infection center and two additional groups were active adjacent to it. Although some overlap did occasionally occur, each group maintained its own territory and remained in it most of the time.

In 1975, six red squirrels were color-marked and retrapped several times within the area. Visual observations and marking and trapping data showed that red squirrels occupied a relatively small home range of 0.4 to 0.8 ha.

Telemetry

When radio transmitters were attached with eyelash cement, surgical glue, and tail clip mounts, they easily dislodged. The strap harness used in 1973 was discontinued because it was difficult to put on birds and did not fit properly. However, the modified woodcock back-pack harness was easily put on a bird, fit well, and was used successfully throughout the study on several birds (figs. 20-22). There was no evidence of chafing or other injury to birds due to the harness or radio transmitter. Birds quickly adjusted to the radio transmitter packages, their social and feeding behavior did not appear to be adversely affected, and they did not lose weight.

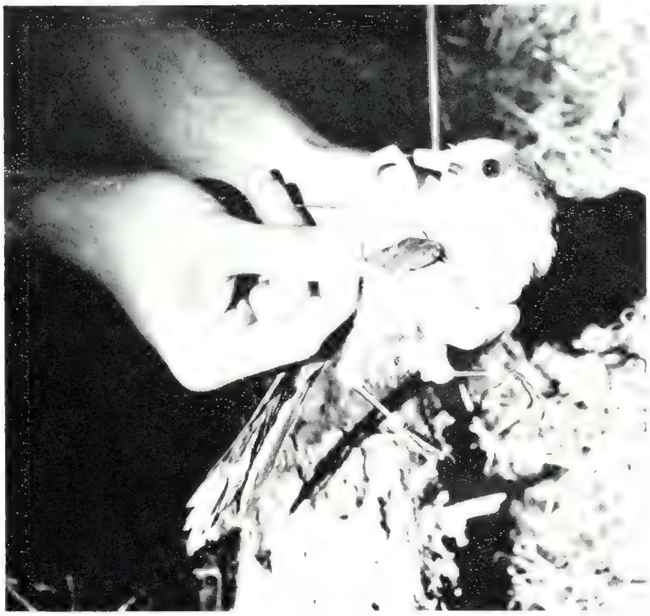

Figure 20.—*Placing radio transmitter onto back of gray jay.*

A total of 115 data days were obtained on the 14 birds with radios. Comparisons of visual sightings with radio fixes on the same bird at a given time indicated that the tracking system using the firefinders was accurate to ± 83 m.

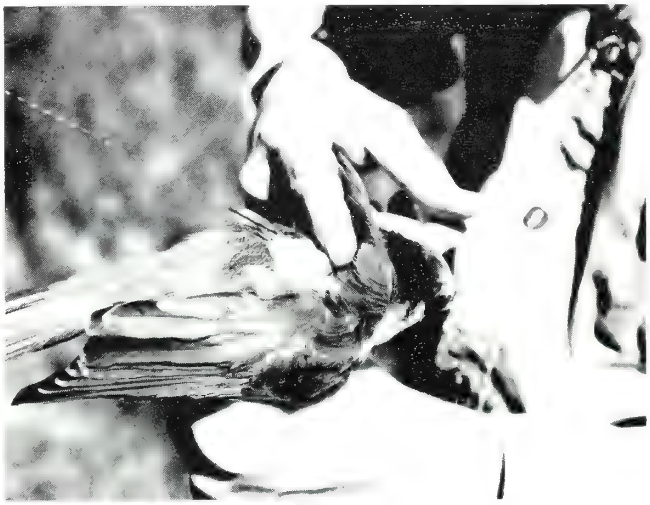

Figure 21.—*Position of radio transmitter on back of gray jay.*

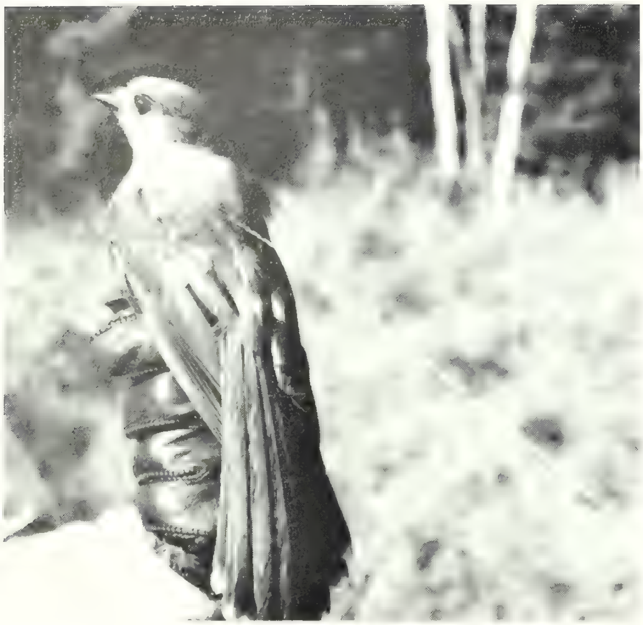

Figure 22.—*Gray jay with radio transmitter in place before release.*

Directional radio fixes obtained in 1973 with hand-held antennas provided information on the general location of home ranges of three gray jays. The jays used the main mistletoe infection center near Spirit Lake but each used a slightly different part of the remaining spruce stand.

The approximate 1974 home ranges of individual gray jays ranged from 8 to 21 ha as exemplified in figure 23. Home range, defined by Burt (1940), is that area used regularly by a bird during activities such as food gathering, seeking shelter, and rearing young. Because in this study gray jays were not monitored throughout the year, home range was described in terms of an activity radius as explained by Odum *et al.* (1955). It was evident that gray jays used all parts of their home range, spending much of their time in mistletoe infection centers. For example, two radio-tagged gray jays were trapped seven times with one or more mistletoe seeds on their bodies (fig. 24). There was only a small overlap in the home ranges of individual gray jay family groups. Thus, each family group had a high degree of exclusive use of their home range, which could be classified as a territory as defined by Pitelka (1959). Gray jays were most active during morning hours, the hours when most mistletoe seeds are dispersed (Hudler and French 1976).

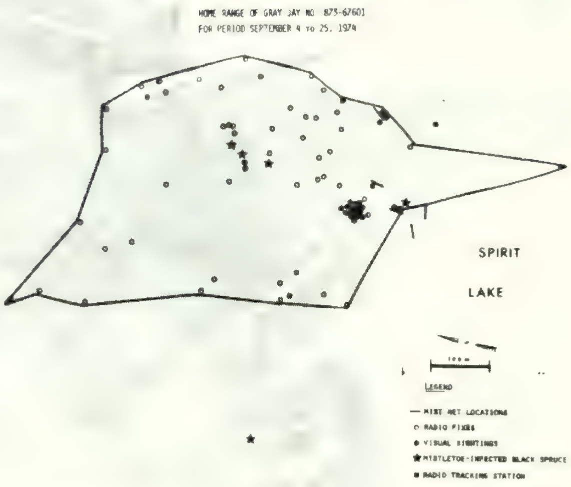
HOME RANGE OF GRAY JAY NO 873-67601
FOR PERIOD SEPTEMBER 4 TO 25, 1974
SPIRIT
LAKE
100 m
LEGEND
— MIST NET LOCATIONS
○ RADIO FIXES
● VISUAL SIGHTINGS
★ MISTLETOE-INFECTED BLACK SPRUCE
■ RADIO TRACKING STATION

Figure 23.—*Home range of gray jay No. 873-67601 for the period of September 4 to 25, 1974, was 21 ha based on 50 radio fixes and 23 visual sightings.*

Infection patterns in the study area and the movements of gray jays, as determined by radio telemetry, were similar in many instances. Isolated mistletoe-infected trees were present along a drainage ditch east of the main infection center. Many radio fixes as well as visual observations indicated that gray jays frequently used this area presumably to search for insects that were common near the open water. Gray jays were observed preening while perched on trees along the ditch.

Animal Behavior

Field Observations

Mistletoe seeds were dispersed in the area when resident birds and squirrels gathered and stored food.

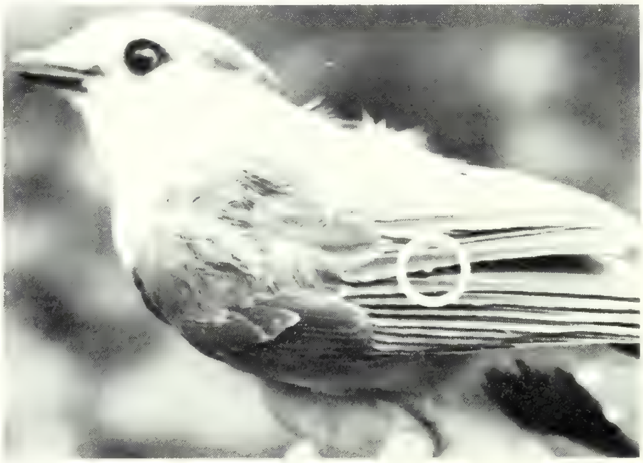

Figure 24.—*Radio-tagged gray jay recaptured with a seed adhering to a primary wing feather.*

At no time were birds or other animals seen searching for or eating mistletoe seeds or shoots.

Seed dispersal coincided with the southern migration of many bird species through the area in 1974. Warblers were predominantly active in infection centers and could be observed foraging for insects within dead and dying mistletoe-infected trees. At times as many as 50 to 100 warblers could be seen searching for food within seed-bearing brooms of infected trees.

Red squirrels were observed gathering and storing spruce cones during this time, jumping from broom to broom and from tree to tree during their foraging, often triggering seed discharge. Six red squirrel nests and a robin's nest were found in brooms.

All birds were observed preening and bill-wiping during and after feeding. Gray jays spent much time preening their feathers and bill- wiping, usually while in the tops of spruce.

Birds and squirrels used all parts of trees from low lateral branches to terminal leaders when foraging and perching. Boreal chickadees *(P. hudsonicus)* foraged directly in mistletoe brooms more frequently than other species. Chickadees hopping around within infected trees discharged many seeds. Food gathering and storage by gray jays brought them into contact with infected and healthy trees. Visual observations indicated that areas used for storing food were free from mistletoe infection. Less bird activity was observed in dense, healthy portions of the stand. However, in large and small mistletoe infection centers, warblers, chickadees, and gray jays were common, probably because more insects were available in the infected and dead trees.

Food Preference Study

Juncos and chickadees did not eat mistletoe seeds. When given mistletoe seeds, berries, and mistletoe shoots only, both bird species picked up seeds but never swallowed them. At the end of the trials, 81 percent of the mistletoe seeds put in the feeding trays were accounted for. This indicates that the birds ate mistletoe seeds only occasionally and then only if no other source of food was readily available.

Force-feeding birds provided evidence that mistletoe seeds may not be palatable to them. When mistletoe seeds were placed at the back of the mouth, the bird would use its tongue to work it forward and then would spit it out. In all instances, seeds were not readily accepted and were either immediately spit out whole or smashed with the bill. Birds readily ate cracked corn after being offered mistletoe seeds.

Seed Movement Study

Of the 660 mistletoe seeds placed on branches of spruce trees, 177 of them were removed. Of these, 96 (12 percent) were unaccounted for. Most likely, the seeds were smashed in such a way as to render them unidentifiable. As was observed in the field, the chickadees in the enclosure spent much of their time searching branches and needles of trees for food. They often pecked at the seeds and removed many of them. At times as many as six or more seeds were picked off branches, smashed, and then spit out. Only rarely did it appear that these smashed seeds were swallowed.

Birds on several occasions removed seeds from one tree, flew to another, and either smashed or dropped them intact while perched in that tree. Seeds were found at the base of trees that had no seeds placed on their branches, but, none were found adhering to branches. On trees that had mistletoe seeds placed on them, some branches had more seeds adhering to them than were originally placed there.

Bird Preening Study

Birds released into the enclosure without seeds on their bodies periodically preened and groomed their feathers and consistently bill-wiped after feeding and drinking. However, birds released into the enclosure with seeds on their bodies preened and bill-wiped much more often and longer. Seeds on the bill and head were removed immediately by bill-wiping and rubbing the head against a branch. The last seeds to be removed were either inaccessible or not bothersome such as those on the upper or lower tail coverts or under the wings. Several times seeds were found on birds 48 hours after they had been put on. A total of nine seeds, seven from juncos and two from black-capped chickadees, were found tightly attached to spruce needles and branches as a direct result of preening and bill-wiping. These seeds were on susceptible portions of the trees and positioned so that they could have caused infections if they would have been allowed to germinate (fig. 25).

DISCUSSION

All of the satellite infection centers examined were too far from the main infection center and from each other to have originated from the explosive discharge of mistletoe seed. This indicates that some other agent was involved in seed dispersal.

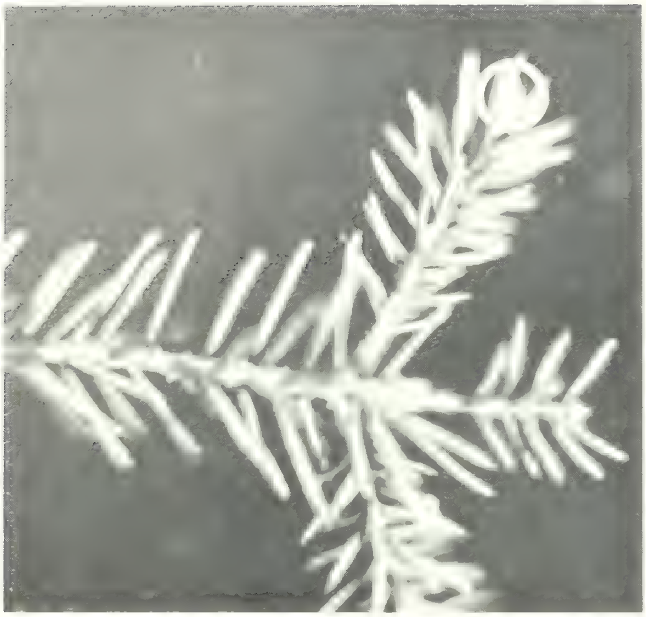

Figure 25.—*Twig taken from potted tree used as a perch in enclosure in the captive bird studies. Black light was used to locate fluorescent-dyed mistletoe seed wiped onto branch during preening.*

Wind may influence local spread of dwarf mistletoe within a center (Parmeter and Scharpf 1972) but is not thought to be responsible for establishing isolated satellite infection centers (Hudler and French 1976). The random location of satellite centers in the Spirit Lake area and distances from other infection centers support this theory (Ostry 1978). Birds and squirrels active within areas of mistletoe infection were identified as important agents responsible for the type of infection pattern present. Bird activity, particularly that of the gray jay, was high in all areas where satellite infections were found.

Many factors, both biological and physical, limit the number of satellite infection centers that arise from vector-borne seeds. These factors may explain why relatively few satellite centers are present even though many animals come into contact with mistletoe seeds.

In the Spirit Lake area most of the satellite infection centers were fairly large and easily located with large-scale aerial photography. However, when only a few infected trees were present, it was extremely easy to miss seeing them on the ground and often impossible to detect them on aerial photographs.

A single, vector-borne staminate infection could remain undetected throughout the rotation of a stand, as could scattered pistillate-infected trees. Only when several infected trees die, opening the crown canopy, does mistletoe infection become evident in a stand. Depending upon the vigor and age of the hosts, it may take many years for mistletoe to develop, spread, and eventually kill a tree. As a result, many vector-borne infections may go unnoticed.

If no vector were involved, dwarf mistletoe infection would slowly radiate out from the initial point of infection. This is not the pattern seen. Instead, dwarf mistletoe infection resembles the pattern of infection seen in the true mistletoes. This pattern consists of many secondary infections resulting from animal activity that develop away from the initial infections. Considering the distances and locations of satellite infection centers in the Spirit Lake area and elsewhere, there is little doubt that vector-borne seed and subsequent infection augment the spread of dwarf mistletoe seed.

Birds and squirrels are important in spreading dwarf mistletoe seed to new areas, but they are even more so in intensifying infection within trees and a local area. Birds and squirrels in infection centers come into contact with seeds when they forage for food, build nests, or perch in infected trees. They often trigger seed discharge as they jump or hop in brooms.

Our study of animals trapped during the time of seed dispersal indicated that seeds can adhere to fur or feathers and be carried to and deposited on healthy trees. Results of the captive bird study supported this hypothesis.

Seeds on the head of a bird are removed quickly. Seeds on parts of the bird's body which are hard for it to reach or that have dried deep in the feathers are left on longer. These seeds are only removed after several thorough bathings. Some seeds were found on birds 2 days after placement. This indicates that seeds could be carried great distances by migratory birds before being removed. These birds, perched on portions of trees susceptible to mistletoe infection, could inoculate trees during bathing and preening activities.

Under humid conditions such as heavy dew, wet snow, or rain, seeds adhered to birds active in infected trees, and several seeds were found on birds after all brooms had stopped discharging seeds. This post dispersal period lengthens the period of time in which a bird or squirrel is likely to come into contact with seeds. All the seeds found on squirrels were on the surface of their fur. Seeds adhering lightly to their bodies could easily be transferred to healthy foliage during their foraging.

In 1975 mistletoe fruits matured early and the peak seed dispersal period began on September 8, 10 days earlier than in 1974. Migrating birds were just beginning to pass through the study area. Some of these species were not trapped in the area until long after the seeds had been discharged. Thus, resident birds such as gray jays were presumably more important as potential vectors. Species of birds acting as vectors may vary from year to year depending upon the timing of seed dispersal in relation to migration patterns of the various species. A possibility exists that migrating birds could spread *A. americanum,* found on jack pine in southern Ontario and Manitoba, to jack pine in the Lake States. Jack pine is a major species in the Lake States and the introduction of *A. americanum* by bird vectors could threaten this resource.

Involvement of vectors has management implications in controlling this parasite. Animal vectors can increase the rate of spread and intensification of dwarf mistletoe infection locally. Once established, each center of dwarf mistletoe infection will remain an inoculum reservoir for future infections. It may be necessary to control these small centers within a stand to prevent additional centers from developing as a result of vector-borne seed (Ostry and Nicholls 1979a). To protect commercially valuable stands from vector-borne infections, control measures may also be warranted in black spruce sites of marginal value that serve as reservoirs for the parasite. This would be especially important if the commercial stand was early in its rotation (Johnston 1977).

Gray jays use infection centers as small as 20 m^2. From a management standpoint this means a small center overlooked in a control program may provide inoculum that could be spread by birds to other parts of the stand. Birds are attracted to stand edges, especially to mistletoe-infected trees that support large numbers of insects. For this reason, it is important to eliminate all infected trees and trees that may have latent infections.

CONCLUSIONS

1. Birds and squirrels use mistletoe-infected trees for nesting and food-gathering. They probably do not eat mistletoe seeds.
2. Mistletoe seed dispersal often coincides with the period of peak animal activity.
3. Openings in spruce stands resulting from mistletoe-killed trees are used more than healthy portions of a stand by many bird species.
4. Mistletoe seeds discharged from their berries can stick to the fur or feathers of animals.
5. Previously discharged seeds adhering to branches can be inadvertently picked up on the bodies of foraging animals under conditions of high humidity.
6. Preening and hygienic habits of birds are responsible for seeds being deposited onto healthy trees.
7. Birds and squirrels are important in intensifying mistletoe infections in localized areas due to their activities during seed dispersal. Gray jays may be one of the most important species responsible for initiating new satellite infection centers.
8. Migrating birds may disseminate mistletoe seed over long distances.
9. The pattern and distribution of some satellite infection centers result from the activities of animal vectors.
10. In some management situations, small centers of mistletoe infection should be controlled to minimize vector-borne infections.
11. Radio telemetry techniques and equipment can be effectively used to study small avian vectors of pathogens.

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Animal vectors of eastern dwarf mistletoe of black spruce. Res. Pap. NC-232. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 16 p.

Describes a study to determine the importance of animals in the spread of eastern dwarf mistletoe of black spruce. Radio telemetry, banding, and color-marking techniques were used to study vectors of this forest pathogen.

KEY WORDS: radio telemetry, disease, parasite, *Perisoreus canadensis,* forest management.

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Survival Predictions for Major Lake States Tree Species

Roland G. Buchman

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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SURVIVAL PREDICTIONS FOR MAJOR LAKE STATES TREE SPECIES

Roland G. Buchman, *Biometrician*

A tree's likelihood of surviving competition from its neighbors and the cumulative tree risks within a stand provide essential forest management information. Such information partially explains the development of the stand and the products available. Past diameter growth and current diameter, individual tree characteristics commonly recorded during a forest inventory, are the essential elements for obtaining tree survival information from the model used in this paper.

The model and survival information in this paper are supported by an extensive data set (table 1). The model is based on the logistic function, which has been extensively used for mortality modeling (Buchman 1979, Hamilton 1980, Monserud 1976); however, it includes a special adaptation that more realistically reflects the survival behavior of small trees and large, slow-growing trees (Buchman *et al.* in press). Individual tree survival rate predictions for many Lake States species have been reported elsewhere (Buchman 1979, Lanford 1975, Letourneau 1979). However, none of these studies used a data set with the strength of this study. Furthermore, the models used in the earlier studies failed to produce realistic survival responses for large, slow-growing trees.

The survival predictions presented in this paper reflect an individual tree's survival under normal or regular life stresses. This includes competition with neighboring trees for moisture, nutrients, and light. It also includes outside effects of endemic pest levels and moderate moisture deficits. However, these predictions do **not** apply when outside effect of pests or environmental conditions exist at catastrophic levels.

This paper presents a model with coefficients for 10 Lake States tree species to enable prediction of an individual tree's probability of survival. The performance of the model is documented on a regional basis across the Lake States and on a local basis for particular forest areas or stands.

METHODS

Data Base

Permanent growth plot tree records were available for the major forest tree species of the Lake States from research cutting experiments, demonstration woodlots, industrial continuous forest inventories, and personal records of forest growth (Christensen *et al.* 1979). Records for a tree were used if three measurements were available on that tree, with it being alive on the first two and not cut before the third measurement. The period between pairs of measurements had to be at least 2 but no more than 6 years.

The first two measurements were used to calculate diameter growth rate (DGR) by dividing the difference in the two diameters by the number of intervening years; zero was recorded if the calculated growth was negative. The second diameter was used as the diameter at breast height (DBH) value. The third measurement was used to record tree status (alive or dead but not cut).

Many trees had more than three measurements that met the time and status requirements. These trees were used as two or more observations of tree status, diameter growth rate, and diameter (table 1).

The data were assembled into DGR-DBH classes for each species using 0.02-inch (0.05-cm) increments for DGR and 1-inch (2.54-cm) increments for DBH. Mean DGR, mean DBH, and number of trees were determined for each class.

Once DGR-DBH classes had been established, we calculated the survival rate (SR) for each class. In

Table 1.--Tree survival data sources

(In number of tree records)

Tree species	Total[1]	North Central Minnesota (research)	Wisconsin (timber harvest forest)	Wisconsin (private woodlot)	Wisconsin (forest industry)	North East Wisconsin (research)	Lower Michigan (research)
Jack pine	2,960	1,206	2	0	191	0	1,561
Red pine	39,998	20,096	114	0	265	1,300	18,223
White pine	2,394	1,531	710	0	149	4	0
Balsam fir	6,776	1	63	0	399	6,313	0
Red maple	2,233	14	548	690	520	461	0
Elm	4,337	26	622	872	201	2,616	0
Basswood	4,056	62	746	485	381	2,382	0
Sugar maple	17,211	0	3,202	682	854	12,473	0
Quaking aspen	6,008	3,684	129	5	825	1,365	0
Paper birch	1,626	24	29	0	321	1,252	0

[1] Number of tree records, several records for some trees.

general, each class had two or more interval lengths for status measurements. Hence, annual survival rates were calculated using the formula:

$$SR = (\Sigma X_i / \Sigma N_i)^{(\Sigma N_i / \Sigma i \cdot N_i)} \qquad (1)$$

where N_i and X_i are the number of trees alive at the beginning and at the end of the status observation interval and i is the interval length (years).

Species Coefficients

These annual survival rates were modeled using

$$SR = b_1 - [1/(1 + e^{n})] \qquad (2)$$

where n is $b_2 + b_3 \cdot DGR^{b_4} + b_5 \cdot (DBH-1)^{b_6} \cdot e^{b_7 \cdot (DBH-1)}$ and $b_1, \ldots, b_7$ are numerical constants. Data for each species were analyzed separately to provide species-specific coefficients for $b_1, \ldots, b_7$.

Note that b_1 sets the maximum SR for a species and cannot exceed 1. Its value was established as a composite survival rate calculated from fast-growing trees of the species. b_2, in concert with b_1, sets the SR for 1 inch trees showing no perceptible growth. Its value was set by extending a free hand curve from the SR data points back to the 1 inch point. The remainder of the coefficients were obtained using nonlinear least-square regression techniques weighted by number of trees. b_3 and b_4 describe the effect of DGR on survival rate for trees that are neither fast growers nor nongrowers. b_5, b_6, and b_7 describe the SR line for those trees growing little or not at all in diameter. Coefficients were calculated for each species.

REGIONAL PERFORMANCE

The data for each species came from across the Lake States (table 1); the coefficients developed could well be termed "regional".

Coefficient Adjustment

The model was applied to the data for each species using the tentative species coefficients developed through regression analysis. Total surviving trees for each DGR and DBH class were counted and compared with those predicted by the model. Adjustments were made in b_3 and b_4 coefficients to shift predicted totals where the differences between the counts and the predictions showed a series of positive or negative values. These adjustments had little effect on the size of the sum of the squared residuals. For the remainder of the paper, model refers to equation (2) and the particular species coefficients (table 2).

DGR Results

Tree-record data were assembled into 12 DGR classes for each species; annual survival rates were predicted by the model and calculated from the data for each class (table 3). Predicted rates were determined by applying the model to the data for each species to get the survival probability for each tree-record within the class, summing these probabilities to get ΣX_i; and then using the SR (1) equation. Calculated rates were obtained by summing the tree status codes (alive = 1, dead = 0) to get ΣX_i and again applying SR (1). In each case N_i is the number

Table 2.--Model (2)[1] coefficients for predicting annual tree survival from diameter growth rate (DGR) and diameter at breast height (DBH)

	Coefficients						
Species	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Jack pine	0.9966	0.5902	0.1800E+2	0.7110E+0	0.1144E-1	0.4764E+1	0.6834E+0
Red pine	.9997	1.9953	.5797E+2	.1012E+1	.2648E+0	.1626E+1	.1273E+0
White pine	.9989	1.6150	.1568E+4	.2268E+1	.8712E+0	.4320E+0	.1012E+0
Balsam fir	.9984	1.9241	.2871E+2	.1021E+1	.4421E+1	.3640E+1	.1672E+1
Red maple	.9964	1.0260	.3686E+3	.1725E+1	.3448E+0	.1968E+1	.2919E+0
Elm	.9941	0.5794	.1163E+2	.6440E+0	.2655E+0	.2963E+1	.4715E+0
Basswood	.9979	1.1097	.2839E+2	.1045E+1	.4035E+0	.2039E+1	.2769E+0
Sugar maple	.9979	2.4852	.6076E+2	.1205E+1	.8503E+0	.1010E+1	.2394E+0
Quaking aspen	.9908	0.3772	.3455E+2	.1089E+1	.9314E-1	.3419E+1	.5346E+0
Paper birch	.9991	1.9539	.8379E+1	.3982E+0	.1710E+1	.2444E+1	.8923E+0

[1] $SR = b_1 - [1/(1+e^n)]$

where n is $b_2 + b_3 \cdot DGR^{b_4} + b_5 \cdot (DBH -1)^{b_6} \cdot e^{-b_7 \cdot (DBH-1)}$

and $b_1, \ldots, b_7$ are species constants.

of tree records at the beginning of the status recording interval (table 3).

Comparison of predicted annual survival rate with the calculated rate shows them to be within 0.005 of each other in 103 of the 120 classes (table 3). Seven classes show differences greater than 0.01. Jack pine and quaking aspen show the greatest differences.

One can approximate the effect of prediction errors using the table entries. To illustrate, suppose you have 100 trees in a selected DGR class and the number of years in your prediction interval is 5. If the calculated survival rate is 0.9829 and the predicted survival rate is 0.9878 (these are the quaking aspen entries for DGR of 0.14 in table 3), the calculated number of trees surviving after 5 years is 91.7 (0.9829^5 x 100) while the predicted number is 94.0 (0.9878^5 x 100). The consequences of the errors in prediction on a stand depend on the mix of trees by species and DGR classes and will be more complicated to evaluate. The differences for adjoining classes often have opposite signs and will provide offsetting errors within the stand.

DBH Results

Tree-record data were assembled into as many as 21 DBH classes by species. The number of records and the DBH distribution for a species determined its number of classes. Two survival rates were calculated for each DBH class using the same procedures as for DGR classes (table 4).

Comparison of predicted annual rate with the calculated rate shows them to be within 0.005 of each other in 115 of the 152 classes. Fourteen show differences greater than 0.01. Differences are largest for small trees, with 0.06 for jack pine, 0.04 for balsam fir, 0.15 for red maple, and 0.12 for quaking aspen.

The consequences of the errors in prediction can be evaluated similarly to that for DGR. However, differences for adjoining DBH classes do not negate each other to the extent they do for DGR classes.

LOCAL PERFORMANCE

Coefficients based on regional data may be applicable to local forested areas or stands. To evaluate this, the performance of the model was tested on data for each species for at least one local forest area (table 5).

Survival results were calculated for each plot within the stand by accumulating the individual predicted tree probabilities (table 5). The observed survival was counted. Predicted survival was determined using the model on each tree's measured DGR and

Table 3.--Measured and predicted annual tree survival rates by diameter growth rate (DGR) for 10 Lake States tree species

		Species									
DGR[1] (In/Yr)	Survival rate[2]	Jack pine	Red pine	White pine	Balsam fir	Red maple	Elm	Basswood	Sugar maple	Quaking aspen	Paper birch
0.00	Mea.	0.7237	0.9666	0.9331	0.9296	0.9336	0.9165	0.9480	0.9685	0.7990	0.9425
	Pre.	.7114	.9665	.9301	.9361	.9321	.9152	.9501	.9680	.8027	.9435
	Base[3]	60	981	87	259	66	352	217	1,008	189	158
.02	Mea.	.8301	.9929	.9383	.9551	.9539	.9471	.9711	.9811	.8450	.9912
	Pre.	.8693	.9916	.9417	.9625	.9566	.9634	.9684	.9804	.8588	.9900
	Base	103	1,237	73	464	79	156	139	521	348	200
.04	Mea.	.9348	.9975	.9776	.9809	.9935	.9711	.9813	.9871	.9171	.9896
	Pre.	.9289	.9969	.9624	.9788	.9762	.9739	.9783	.9875	.9076	.9940
	Base	104	2,224	88	550	132	352	263	1,206	369	209
.06	Mea.	.9643	.9992	.9864	.9907	.9911	.9832	.9876	.9930	.9552	.9972
	Pre.	.9616	.9991	.9902	.9877	.9917	.9806	.9876	.9933	.9468	.9964
	Base	101	3,777	111	648	168	290	200	1,084	428	204
.08	Mea.	.9576	.9992	.9925	.9930	.9948	.9869	.9894	.9945	.9794	.9978
	Pre.	.9762	.9995	.9981	.9922	.9955	.9841	.9923	.9958	.9695	.9970
	Base	178	5,038	128	663	207	342	271	1,642	389	180
.10	Mea.	.9890	.9994	.9985	.9949	.9977	.9864	.9960	.9977	.9767	.9979
	Pre.	.9836	.9997	.9989	.9948	.9963	.9883	.9954	.9971	.9806	.9976
	Base	337	5,682	158	1,002	278	408	378	2,236	436	196
.12	Mea.	.9990	.9997	.9937	.9969	.9935	.9861	.9990	.9988	.9828	.9984
	Pre.	.9897	.9997	.9989	.9964	.9964	.9890	.9965	.9976	.9857	.9978
	Base	274	4,317	115	622	194	233	210	1,020	365	124
.14	Mea.	.9874	.9997	.9960	.9979	.9990	.9896	.9959	.9978	9829	1.0000
	Pre.	.9920	.9997	.9989	.9972	.9964	.9906	.9971	.9978	.9878	.9978
	Base	331	4,551	173	557	215	313	368	1,724	409	96
.16	Mea.	.9961	.9997	1.0000	.9963	.9956	.9907	.9961	.9979	.9849	.9970
	Pre.	.9935	.9997	.9989	.9976	.9964	.9910	.9973	.9978	.9893	.9979
	Base	314	3,549	194	481	197	251	286	1,403	460	68
.18	Mea.	.9957	.9996	.9947	.9975	.9974	.9889	.9994	.9986	.9864	1.0000
	Pre.	.9945	.9997	.9989	.9979	.9964	.9924	.9976	.9979	.9901	.9980
	Base	298	2,802	169	388	171	275	378	1,361	479	56
.20	Mea.	.9962	.9998	.9987	.9989	.9985	.9965	.9980	.9982	.9897	1.0000
	Pre.	.9952	.9997	.9989	.9981	.9964	.9927	.9977	.9979	.9904	.9981
	Base	376	1,998	180	356	152	348	425	1,418	467	56
Rest[4]	Mea.	.9972	.9996	.9995	.9985	.9957	.9961	.9978	.9967	.9914	1.0000
	Pre.	.9962	.9997	.9989	.9983	.9964	.9935	.9979	.9979	.9907	.9983
	Base	484	3,811	918	783	374	1,014	918	2,587	1,669	77

[1] Upper limit of DGR interval, first interval contains trees of no measurable growth.

[2] Measured annual survival rate and the predicted annual survival rate.

[3] Number of tree records.

[4] Includes all trees growing more than 0.2 inch per year.

DBH; the resulting probabilities for surviving 1 year were raised to the nth power to get the probability of surviving for n years.

Performance, as measured through several statistics calculated from the number of trees, is based on plot results within the stand. The observed and predicted stand average of the number of trees surviving after n years is presented along with the initial number of trees. The standard deviation of the differences between observed and predicted trees per plot is shown. Finally, the slope of the line for regressing estimated trees from observed trees is given. A slope value of one shows that differences between the observed and predicted tree counts are uniform for the range of plot tree counts.

The observed and estimated number of trees surviving within each stand agree closely (table 5). Although jack pine and quaking aspen show several

Table 4.--Measured and predicted annual tree survival rates by diameter class (DBH) for 10 Lake States tree species

		Species									
DBH[1] (In)	Survival rate[2]	Jack pine	Red pine	White pine	Balsam fir	Red maple	Elm	Basswood	Sugar maple	Quaking aspen	Paper birch
1	Mea.	0.9043	0.9356		0.9966				0.9312		
	Pre.	.8444	.9295		.9545				.9498		
	Base[3]	62	18	0	208	0	0	0	53	0	0
2	Mea.	.9676	.9475		.9823	0.7986	0.8651	0.8867	0.9683	0.8804	0.9790
	Pre.	.9556	.9513		.9789	.9433	.8443	.8889	.9745	.7599	.9782
	Base	426	133	0	1,337	7	29	34	620	31	423
3	Mea.	.9720	.9808		.9932	.8864	.8922	.9428	.9875	.8786	.9942
	Pre.	.9712	.9768		.9949	.9763	.9112	.9486	.9856	.8391	.9949
	Base	851	320	0	1,678	4	127	63	794	161	364
4	Mea.	.9826	.9841	.9686	.9961	.9697	.9441	.9758	.9904	.9063	.9974
	Pre.	.9779	.9983	.9532	.9960	.9700	.9446	.9667	.9908	.9061	.9964
	Base	482	1,254	48	1,276	43	279	192	1,709	581	235
5	Mea.	.9840	.9954	.9592	.9962	.9873	.9819	.9822	.9946	.9443	.9894
	Pre.	.9867	.9958	.9626	.9943	.9828	.9759	.9858	.9943	.9490	.9955
	Base	447	3,080	109	850	169	371	318	2,490	706	136
6	Mea.	.9857	.9988	.9748	.9909	.9948	.9909	.9897	.9966	.9740	1.0000
	Pre.	.9918	.9985	.9768	.9916	.9941	.9884	.9931	.9963	.9740	.9965
	Base	376	5,374	101	659	342	406	413	2,817	884	162
7	Mea.	.9822	.9995	.9899	.9882	.9929	.9950	.9946	.9957	.9838	.9953
	Pre.	.9913	.9992	.9878	.9919	.9939	.9913	.9957	.9970	.9842	.9961
	Base	198	6,336	95	403	291	429	451	2,234	991	135
8	Mea.	.9731	.9997	.9979	.9819	.9935	.9968	.9971	.9965	.9836	1.0000
	Pre.	.9850	.9995	.9918	.9894	.9939	.9917	.9969	.9970	.9860	.9966
	Base	47	5,639	120	187	270	460	466	1,717	906	71
9	Mea.	.9790	.9996	.9958	.9730	.9966	.9948	.9985	.9973	.9850	.9954
	Pre.	.9855	.9996	.9937	.9932	.9942	.9923	.9973	.9970	.9883	9954
	Base	30	4,971	128	109	258	437	439	1,142	693	47
10	Mea.	.9849	.9997	.9916	.9785	.9931	.9835	.9974	.9969	.9872	.9956
	Pre.	.9878	.9996	.9978	.9944	.9912	.9914	.9971	.9965	.9882	.9961
	Base	41	3,950	120	66	219	429	410	845	512	51
11	Mea.		.9996	.9930		.9941	.9834	.9970	.9979	.9918	
	Pre.		.9996	.9966		.9913	.9902	.9963	.9964	.9876	
	Base	0	2,805	138	0	181	385	347	611	306	0
12	Mea.		.9998	.9924		.9918	.9837	.9962	.9963	.9869	
	Pre.		.9996	.9974		.9913	.9874	.9952	.9965	.9887	
	Base	0	2,023	155	0	129	284	225	476	146	0
13	Mea.		.9996	.9933		1.0000	.9785	.9925	.9994	.9885	
	Pre.		.9996	.9980		.9922	.9864	.9957	.9963	.9861	
	Base	0	1,440	171	0	75	188	148	369	91	0
14	Mea.		.9998	.9963		.9971	.9847	.9962	.9977		
	Pre.		.9995	.9963		.9920	.9809	.9949	.9967		
	Base	0	948	181	0	69	126	110	286	0	0
15	Mea.		.9997	.9975		.9895	.9671	.9978	.9984		
	Pre.		.9995	.9971		.9908	.9843	.9936	.9958		
	Base	0	715	176	0	59	93	101	277	0	0
16	Mea.		1.0000	9988		.9948	.9908	.9951	.9970		
	Pre.		.9994	.9980		.9927	.9751	.9936	.9951		
	Base	0	461	182	0	117	92	87	223	0	0
17	Mea.		1.0000	.9964			.9818	.9869	.9969		
	Pre.		.9994	.9975			.9715	.9911	.9949		
	Base	0	251	174	0	0	47	69	146	0	0
18	Mea.		1.0000	1.0000			.9817	1.0000	.9982		
	Pre.		.9993	.9988			.9719	.9884	.9949		
	Base	0	134	137	0	0	47	38	125	0	0
19	Mea.		1.0000	.9932			.9755	1.0000	.9976		
	Pre.		.9990	.9979			.9706	.9927	.9939		
	Base	0	60	122	0	0	105	39	93	0	0
20	Mea.		.9963	1.0000				.9851	1.0000		
	Pre.		.9984	.9988				.9801	.9966		
	Base	0	55	70	0	0	0	103	66	0	0
21	Mea.			1.0000					.9873		
	Pre.			.9959					.9941		
	Base	0	0	167	0	0	0	0	117	0	0

---

[1] Midpoint of DBH interval, last entry for a species includes that DBH and larger trees.

[2] Measured annual survival rate and predicted annual rate.

[3] Number of tree records.

Table 5.--Performance of survival rate prediction model for selected forest areas

Stand Description									Survival Results					
					SP[3]	Basal Area		DBH	Beg.		End		Std	
SP[1]	Area and origin[2]			Plots	SI	All	SP	SP	obs.	Yrs[4]	obs.	pre.	dev.[5]	Slope
				no.	ft	ft²/ac		in.	No. of trees					
JP	LP	MICH	RP	50	--	92	92	5.9	487	11	268	328	.5178E+2	1.001
	LP	MICH	RP	10	50	74	74	4.9	542	4	506	480	.2168E+2	0.918
	NE	MINN	RM	49	--	102	65	8.8	163	5	152	142	.1346E+2	0.923
	NE	MINN	RM	49	—	111	68	9.2	157	7	134	128	.1628E+2	0.885
	NW	MINN	RP	20	65	90	90	5.4	589	5	530	530	.2385E+2	1.037
WP	NE	WISC	TN	17	58	83	69	11.9	97	6	94	93	.4670E+1	0.980
	NE	WISC	TN	12	58	76	58	13.9	52	13	49	49	.4690E+1	1.091
RP	NC	MINN	RN	45	52	101	101	10.8	165	5	163	164	.3090E+1	1.005
	NC	MINN	RN	45	52	109	109	13.2	121	5	121	121	.1050E+1	0.996
	NE	WISC	SP	8	65	163	163	6.9	650	6	635	640	.9520E+1	1.030
	NE	WISC	SP	8	65	185	185	9.4	465	6	456	454	.5020E+1	0.989
	NC	MINN	RP	54	70	105	105	8.8	257	5	256	255	.3120E+1	0.988
	NC	MINN	RP	54	70	120	119	10.4	221	4	220	220	.3230E+1	1.008
BF	NE	WISC	RN	25	62	94	37	3.3	582	5	573	566	.6100E+1	0.991
	NE	WISC	RN	10	62	63	55	4.2	538	6	516	518	.1430E+2	0.978
	NE	MINN	RN	46	--	66	17	7.1	61	5	52	56	.9970E+1	0.932
	NE	MINN	RN	42	--	76	21	7.0	77	7	59	66	.1250E+2	1.096
RM	SE	WISC	WN	37	--	97	16	12.0	21	1	21	20	.7500E+0	0.965
		WISC	IN	40	--	59	16	7.5	48	5	46	46	.2650E+1	1.024
	JP	MICH	SN	42	--	64	12	7.8	33	11	32	31	.2330E+1	0.965
EL	NE	WISC	RN	12	77	91	34	8.2	86	6	80	78	.2460E+1	0.988
	NE	WISC	RN	12	77	108	37	9.1	80	5	77	74	.2700E+1	0.981
BW	NE	WISC	RN	12	74	91	9	7.0	29	6	26	26	.1950E+1	0.982
	NE	WISC	RN	12	74	108	11	8.2	26	5	26	25	.8500E+0	0.977
	NE	WISC	FN	49	--	91	31	8.1	84	5	80	81	.6230E+1	0.981
SM	NE	WISC	RN	12	67	91	26	4.8	181	6	168	169	.4870E+1	0.921
	NE	WISC	RN	12	67	108	32	5.5	166	5	162	163	.3340E+1	1.024
	EC	WISC	RN	10	—	70	23	5.4	130	3	120	128	.9260E+1	0.877
	EC	WISC	RN	10	—	84	30	6.0	141	5	139	138	.1060E+1	0.989
	NE	WISC	RN	20	59	73	43	6.9	151	2	150	150	.1680E+1	0.984
	NE	WISC	RN	22	59	82	49	7.7	132	3	131	131	.1700E+1	1.010
	NE	WISC	FN	49	--	93	22	8.1	53	5	52	52	.2910E+1	0.971
	UP	MICH	SN	50	--	90	35	10.2	58	9	56	56	.3520E+1	1.005
QA	NE	WISC	RN	20	--	105	50	5.6	267	5	235	224	.1739E+2	0.893
	NW	MINN	FN	48	--	59	31	8.3	86	7	75	77	.9490E+1	0.946
	UP	MICH	SN	49	--	55	20	8.3	49	11	36	39	.1102E+2	0.970
	NW	MINN	RN	28	80	96	90	7.0	347	5	287	297	.2596E+2	0.958
	NW	MINN	RN	28	80	121	114	9.0	259	5	221	222	.1385E+2	0.950
PB	NE	WISC	RN	20	--	105	9	3.1	177	5	170	170	.5130E+1	1.001
		WISC	IN	46	--	57	9	7.2	35	5	34	34	.1730E+1	0.982
	UP	MICH	SN	38	--	66	15	7.5	47	11	46	45	.4300E+1	0.947

[1] Species:

JP (Jack pine)	EL (elm-american)
WP (white pine)	BW (basswood)
RP (red pine)	SM (sugar maple)
BF (balsam fir)	QA (quaking aspen)
RM (red maple)	PB (paper birch)

[2] Origin:

Column 1	Column 2
F (federal)	N (natural stand)
I (industry - private)	P (plantation)
R (research)	M (mixed)
S (state DNR)	
T (timber harvest forest)	
W (woodlot - individual)	

[3] Site index at age 50 is given for species being analyzed when uniform value was obtained among the plots.

[4] Years in the interval between measuring DGR and DBH and recording status; i.e., the projection interval.

[5] Standard deviation among the plots within the stand.

large differences, with offsetting positive and negative results, each has good agreement on half the stands.

The standard deviation of errors among the plots within each stand shows few large plot errors. The size of these errors is not related to the number of trees on the plot, as shown by the closeness of the slopes to one. Furthermore, the standard error of the mean difference, approximated by dividing the standard deviation by $\sqrt{\text{plot number}}$, is small except for several jack pine stands.

DISCUSSION

The coefficients calculated for the 10 tree species were developed from a data base having strength both in number of trees and in the geographical distribution of plots. The breadth and depth of the data base means that the model can be confidently applied to the broad range of conditions in the Lake States.

Analysis of the model based on DGR reveals very close agreement between predicted and calculated annual survival rates on a regional basis. Projections based on this model show excellent agreement with actual survival when applied for intervals of up to 6 years. Stands, with trees in several growth classes, also show excellent agreement between predicted and calculated survival.

Analysis of the model based on DBH reveals some discrepancies between predicted and calculated survival rates, especially among the small trees for four species. This coincides with the weakest part of the data set. The DBH analysis results, when considered in conjunction with the DGR analysis, suggest the model will perform well except for sites with many small trees.

The model's performance in individual stands, with few exceptions, shows good agreement between observed and predicted tree survival. This suggests that the composition of the regional data base reflects the condition of local stands and supports use of the model over the broad range of Lake States conditions.

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Buchman, Roland G.

Survival predictions for major Lake States tree species. Res. Pap. NC-233. St. Paul, MN: U.S. Deparment of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 7 p.

A model and species' coefficients are reported for predicting individual tree survival for 10 Lake States species. Tree attributes are diameter growth rate and diameter at breast height. Regional and local performances are summarized.

KEY WORDS: Mortality rates, mortality models, survival model, mortality coefficients, tree risk.

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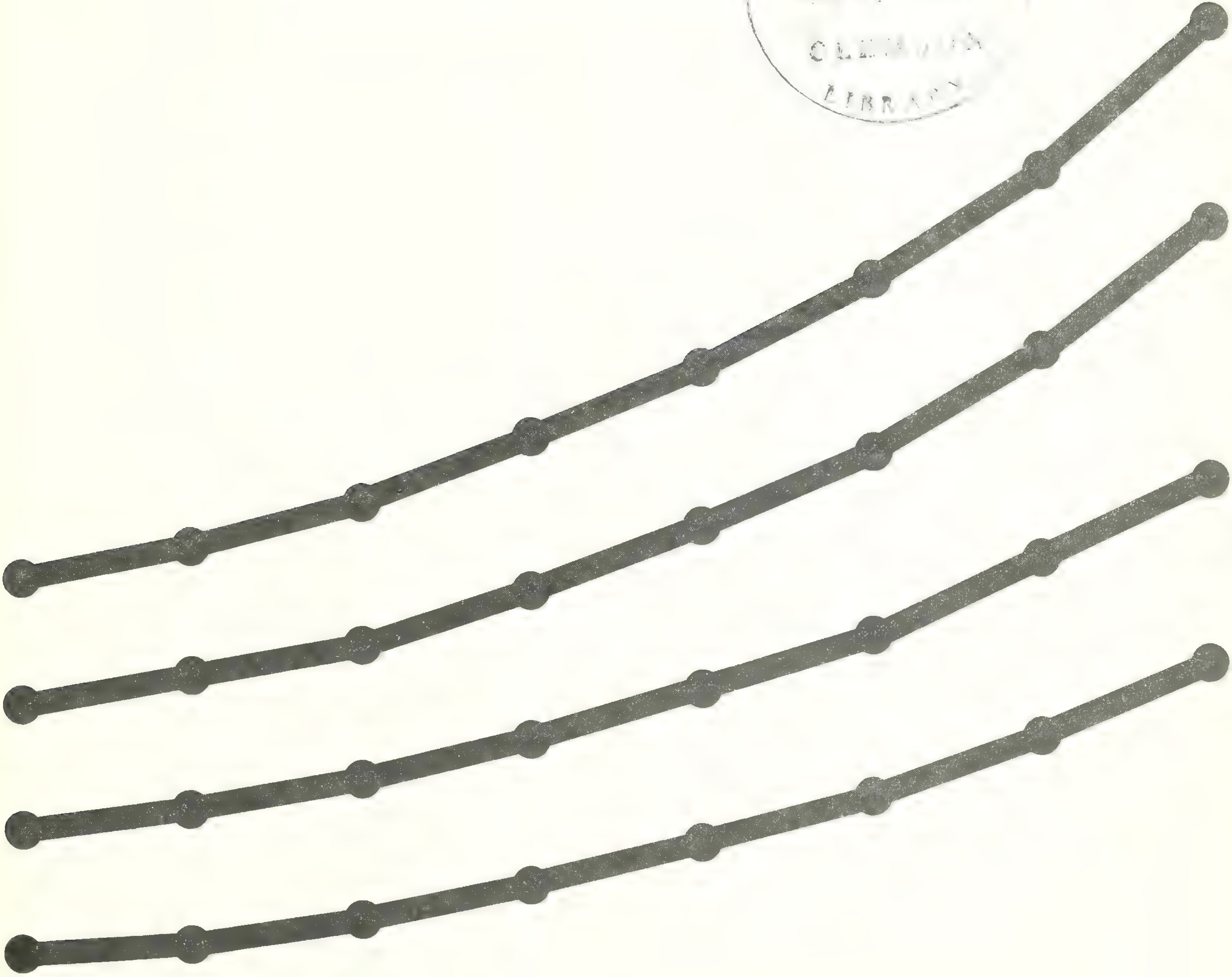

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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An Evaluation of the STEMS Tree Growth Projection System

Margaret R. Holdaway, *Mathematical Statistician*
and **Gary J. Brand,** *Research Forester*

In 1975, research was begun at the North Central Forest Experiment Station to develop a system to project tree growth in the Lake States region. The tree growth projection system developed (USDA Forest Service 1979a) represented just one component of a broader Forest Resources Evaluation Program (FREP). The original projection system (which we will call GTR49) has been modified several times; the current version is STEMS, Stand and Tree Evaluation and Modeling System (Belcher *et al.* 1982).

STEMS is an individual tree, distance-independent model that can be used to project diameter growth and mortality for any species mixture and stand structure. Growth and mortality coefficients have been developed for the major tree species in the Lake States region (Michigan, Minnesota, and Wisconsin). However, because the current version of STEMS contains an incomplete regeneration submodel, it should not be used to project forest stands where *seedlings* are an important component.

Before any model can be used effectively, it must be evaluated. The purpose of model evaluation is to increase one's "confidence in the predictive capabilities of the model" (Schaeffer 1980) or to compare "its agreement with the real-life system it is intended to represent" (Goodall 1972). In the model evaluation process the primary questions include, who is going to use the model and their purpose for using it. As a result, model evaluation is very subjective and there is no absolute test of validity.

Model evaluation should not attempt to determine whether or not a model is acceptable. Because models are used for many different purposes—e.g., studies on competition and succession change, updating inventories, studying the impact of different cutting prescriptions—acceptability will depend on the use. For this reason, a more appropriate approach to model evaluation is to present an extensive body of quantitative information on the model's performance. These results can provide the basis for users to evaluate the model for their own specific purpose.

The purposes of this paper are (1) to provide a brief preliminary analysis of how well the performance of STEMS compares with GTR49, and (2) to report the results of an analysis of the STEMS tree growth projection system for a wide range of forest conditions and identify its main strengths and weaknesses. These conditions encompass a wide range of forest types, species, time intervals, stand densities, and site qualities. Evaluations concentrate on three key variables—tree d.b.h. (evaluates the growth component of the model), number of trees per acre (evaluates the mortality component), and stand basal area (evaluates the entire model). The analysis was performed on a systematic sample from the calibration data base as well as on five independent data sources. The results are presented in a simple format that can be interpreted without specialized statistical knowledge. Belcher, Holdaway, and Brand (1982) have previously reported some preliminary results of STEMS' performance.

EVALUATION PRINCIPLES

Evaluation Philosophy

Modelers need not be concerned with proving the "truth" of a model because no model will behave exactly like the system it is modeling. All models are imperfect; at best they are a simplification of extremely complex biological and ecological processes (Goodall 1972, Goulding 1979, Pilgrim 1975, Taylor 1979, Valentine 1978). The objective, then, of the evaluation process is not to accept or reject the model as true or false but to determine the quality of the predictions (Goodall 1972). There is no absolute test of validity or accuracy of a model but only subjective judgments based on the proposed use of the model, the acceptable level of errors, the availability of alternative models, and other user-related practical considerations. Therefore, we will not be concerned with hypothesis tests but with quantitative statements about accuracy and precision.

Furthermore, models can be expected to fail on some occasions due to oversimplification of assumptions and relations, rarely encountered situations that have not been properly modeled, or extreme conditions that have not been considered. Therefore, it is unwise to base an evaluation of the model's performance solely on prediction errors averaged over all plots without regard to the more subtle discrepancies. A modeler needs to identify those areas in which the model produces fairly reliable results (called the range of applicability) and to highlight the weak areas (Goulding 1979, Pilgrim 1975, and Taylor 1979). One way to do this is to examine patterns of residual errors for various time intervals and various initial conditions (Pilgrim 1975, Taylor 1979). These patterns give much more information about the adequacy of the model than any single test of significance. It is also important to consider the model's performance outside the range of the calibration data and to determine whether the results are consistent with current knowledge. So modelers are not just concerned with how well the model functions, but also with the range of conditions over which it functions well.

Once the user has determined where and under what conditions the model performs adequately, he can judge the model's practical value. This may be a more desirable criterion of acceptance than a statistical measure or test that gives little information on exactly what is happening (Pilgrim 1975, Goodall 1972, Goulding 1979). Thus, the critical question is not whether the model is valid but whether it is useful (Mankin *et al.* 1975).

Therefore, recognizing the subjective, user-dependent nature of model evaluation, our approach is to provide a general overview along with a detailed analysis to assist the user in making that evaluation.

Calibration Data and Independent Data

We believe model evaluation should begin by examining the model's performance on the calibration data base. Any marked bias would indicate a basic flaw in the mathematical model used to describe the system. Leary *et al.* (1979) presented three problem areas that may cause this bias:

(1) the mathematical equations fail to describe parts of the process,
(2) model components are combined incorrectly (i.e., additive or multiplicative), and
(3) the numerical constants obtained from the calibration are in error.

If the model fails at this stage, the model will need to be refined before proceeding with further model evaluation.

A projection system that performs well on calibration data may still fail to satisfactorily fit independent subsets of the region. Therefore, the model should also be tested against independent data before its performance can be accurately assessed (Schaeffer 1980, Taylor 1979). This data should cover as wide a range of conditions as possible.

Comparison of Models

There is no universally accepted criterion against which the model's performance can be compared; validation is never absolute. Furthermore, we often compare the relative performance of two alternative models. This is how models are progressively developed and improved (Goodall 1972). The new model replaces the old if it is judged to perform better.

When comparing alternative models, it is unlikely that one model will give better predictions for all variables over a full range of stand conditions and forest types. For the *user,* the choice of a model will depend on which variables are more important, the amount of bias and variability in the predictions, the seriousness of the problem areas, and many other less obvious factors. The appropriate weighting of these various considerations depends on the purposes for which the model is to be used and is often very subjective and arbitrary (Goodall 1972). For the *model developer* other important considerations include the simplicity of the model, the ease of recalibrating the model, and the number of unknown coefficients to be estimated.

Data Base Differences

Differences between the calibration and validation data bases should be carefully considered when evaluating the model. For example, the types of plots used for the calibration may be different than those used for the validation or new conditions may occur that are outside the range of the calibration data. Problems can also arise if the geographical location of the calibration data is different from the area where the projection system is applied.

Can the yields observed on *experimental* plots be duplicated on general forest land? The tree growth model coefficents were developed mainly from research plots. Such plots usually are chosen for their good location and minimum natural damage and also have been carefully managed so the result is a more uniform stand than would be found on general forest land. Consequently, we would expect the model coefficients to overpredict production when applied to general forest land. Bruce (1977) has noted these growth differences but concludes that "no single magic number" can be used to adjust for it.

Another problem may arise if the model has some weak areas that have no effect in one predictive situation but that surface in another—the model may be valid for one "range of conditions" but invalid for another (Schaeffer 1980). For example, if the data used to calibrate the model did not include very small trees and the model was later used to project growth on these trees, the results may be seriously in error. This type of problem can be evaluated by comparing various initial conditions on the calibration data base and on subsequent validation data sets.

Not only may a model be invalid under a certain range of conditions but also for different geographical locations due largely to climate and soil factors.[1] How can these location differences be handled, especially when the model is applied outside the region in which it was calibrated? One factor in choosing a model form should be the ease in adjusting the coefficients so that they can be altered to account for local conditions. An adjustable model needs to be fairly easy to understand and should not require complex manipulations to change the amount of growth or the relative allocation of growth to trees on a plot.

EVALUATION ATTRIBUTES

Accuracy and Precision

The quality of the predictions made by a tree growth projection system can be analyzed in terms of both accuracy and precision. Predictions with small systematic errors are said to be highly accurate. A common measure of accuracy is the mean error. The mean error can be misleading, though, if there are large offsetting positive and negative random errors. Therefore, a measure of variability is also needed. Predictions with small random errors are considered to be highly precise and hence will be reproducible. The standard deviation (or its square, variance) is the most common of the many measures of precision. Our results will include both accuracy and precision using the mean and standard deviation of the prediction errors.

Evaluation Variables

Judgments about a tree growth model's performance should be based on key variables. We wanted to choose a set of variables that covered the most important aspects of stand and tree growth and that were directly estimated quantities. At the stand level, the key variables we use are stand basal area per acre (BA) and number of trees per acre (NT). Not only is BA an important stand attribute, but it is also an important component in estimating volume. NT is used to evaluate the mortality component, which is important because mortality greatly influences overall model performance. At the tree level, the variable we use is tree d.b.h. (DBH), which is important in management strategies, tree volumes, and mortality estimates. Modelers may find this detailed tree level analysis especially beneficial. Therefore, throughout this paper we will evaluate how well the model predicts BA and NT at the stand level and DBH at the tree level.

Components

When a model has been built from components describing a number of separate processes, it is informative to evaluate the model in a way that will show how well each process is working. In GTR49 and STEMS, DBH measures how well the growth component functions and NT measures how well the mortality component functions. BA, a combination of the two, measures how well the model functions as a whole. Errors in predicting BA can be due to problems in the growth component and/or mortality component. BA prediction could be very good even with large, but cancelling, errors in both DBH and NT. Therefore, it is the indepth evaluation of the separate growth (DBH) and mortality (NT) components that provide the clearest picture of how the system is operating.

A secondary component also needs to be tested. Whenever tree crown ratio is unknown, it is estimated using a crown ratio function. Errors resulting from this approximation are studied in an independent analysis of the crown ratio function.

Time Effect

Continuous growth models will predict nearly perfectly over very short time intervals. The longer the prediction interval, the less accurate the prediction will be (Goodall 1972). Consequently, if the time intervals used in the evaluation vary greatly, it may be difficult to make any justifiable conclusions. Two obvious choices can be made: (1) only use data from plots with similar time intervals or (2) standardize all results to a common time interval, such as 10 years. We have taken the second approach to make full use of the data. Then, we can compare plots with different measurement lengths or pool results together for a general overview. To standardize the time effect we assumed that error decay (the way error changes over time) is linear. We will evaluate this assumption in greater detail later in the paper.

---

[1] *This aspect of the validation process is highly complex and we will not discuss it in this paper.*

Besides standardizing the time effect for most aspects of this study, we also analyzed the time effect in two ways. The first approach is an analysis of error decay on a property with at least three measurements. From this it is possible to analyze how accuracy and precision behave over time. The second approach is a long-term projection to test whether the growth model produces plausible results when extended far beyond the time frame in which it was calibrated.

All the results presented in this paper have been standardized to 10 years except those presented in the section on error decay and long-term projections.

METHODS AND PROCEDURES

Data Bases

The calibration data base consisted of tree measurements from permanent growth plots in the Lake States (fig. 1) (Christensen *et al.* 1979).[2] The plots ranged in size from 0.1 to 0.5 acre. On many of the plots only trees more than 5 inches d.b.h. were remeasured (but this diameter limit was as low as 0.6 inches on some plots and as high as 9 inches on others).

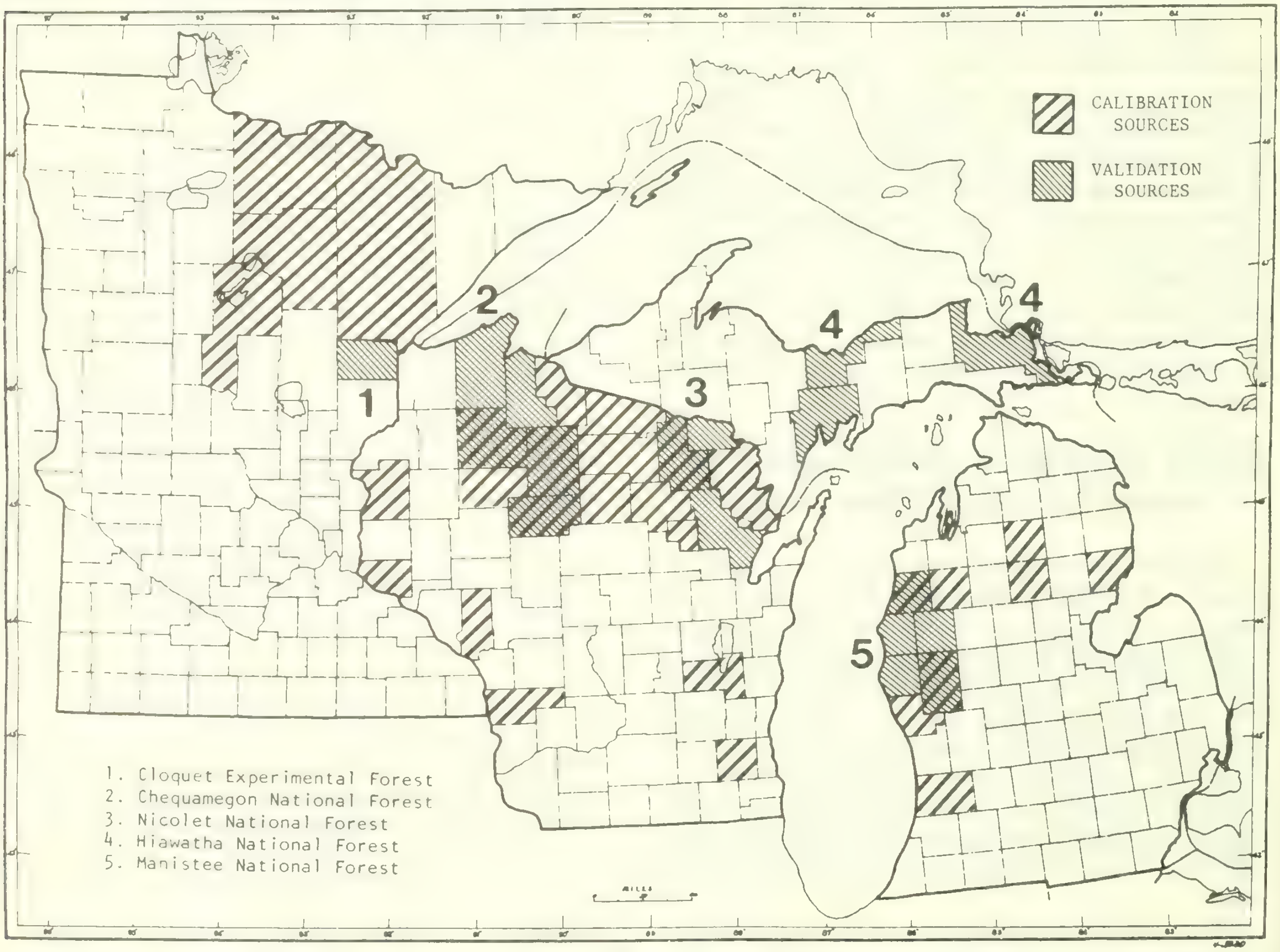
CALIBRATION SOURCES
VALIDATION SOURCES
1
2
3
4
4
5
1. Cloquet Experimental Forest
2. Chequamegon National Forest
3. Nicolet National Forest
4. Hiawatha National Forest
5. Manistee National Forest
MILES

Figure 1.—*Geographical location of the calibration data and the five validation data sources used to test the projection system. Counties are shaded if they contain at least one plot.*

The data from the Lower Peninsula of Michigan are entirely red pine and jack pine plantations. The Wisconsin data are mostly northern white-cedar and natural hardwood stands (oak-hickory type in the south and west and northern hardwoods in the north). There is also a red pine plantation adjacent to the Upper Peninsula of Michigan and a white spruce plantation about 150 miles southeast of it. The northern Minnesota studies include natural and planted red pine and jack pine stands, and natural quaking aspen, white pine, and black spruce stands.

We systematically sampled every fifth calibration plot to yield 293 plots with approximately 7,700 live trees. Only those trees that were alive at the first measurement and were both predicted alive and observed alive at the last measurement were analyzed at the tree level. On the calibration sample, the average initial age was 48 years, the average initial tree diameter was 6.6 inches, and the average time from initial to final measurement was 20 years (fig. 2). The 80+ class for initial age contains observations up to 144 years. The validation data base came from five independent sources or properties in the Lake States (fig. 1):

(1) Cloquet Experimental Forest of the College of Forestry, University of Minnesota;[3]
(2) Chequamegon National Forest, Wisconsin;[4]
(3) Nicolet National Forest, Wisconsin;[4]
(4) Hiawatha National Forest, Michigan;[4]
(5) Manistee National Forest, Michigan.[4]

The Cloquet plots were all one-seventh acre with diameters of all trees more than 4.9 inches recorded. The National Forest plots were 10-point clusters of variable radius plots with measurements on trees 1.0 inch in diameter and larger. All National Forest plots were measured roughly 10 years after the initial measurement.

The total validation data base from the five properties contained 822 plots with nearly 11,200 trees. The average initial age of the plots was 46 years (only 2 years younger than the calibration data), the average initial diameter was 8.2 inches, and the average time interval was 13 years (much shorter than the calibration data) (fig. 2). Again the 80+ class for initial age contains observations up to 196 years.

Each plot in the two data bases contained site index, stand age, measurement dates, and a list of trees. Each tree in the list had a species code, tree factor (trees per acre represented by the tree), and crown ratio code[5], plus for each measurement a diameter and status code (alive, dead, or cut).

Basic Projection Data

We used the following steps to assemble the projection data.

(1) Project the growth from the years of the first measurement to the year of the last measurement, using the tree and stand characteristics at the first measurement as initial conditions for the projection.
(2) Remove a tree from the projection tree list in the same year it was observed to have been cut.
(3) Add a tree to the list of trees being projected in the same year it was observed to be an ingrowth tree.
(4) Write one output file of stand information containing initial conditions along with final predicted and observed conditions.
(5) Write a second output file of similar information for each tree carrying along pertinent stand information.
(6) Use these two files as the basic data for analyzing and summarizing the projection results at both the stand and tree levels.

The basic analysis involved calculating the error (i.e., predicted minus observed value) for a given attribute (DBH, NT, and BA) and then standardizing this error to 10 years using the equation:

$$\frac{\text{(predicted attribute} - \text{observed attribute)}}{\text{number of years in measurement interval}} \times 10.$$

---

[2] *We wish to thank the following persons for making information available to us and/or helping collect field measurements: Carl Tubbs, Dick Godman, Gus Erdman, Gib Mattson, John Benzie, Paul Laidly, and Bob Barse, North Central Forest Experiment Station; Rod Jacobs, USDA Forest Service, State & Private Forestry; Alan Ek, University of Minnesota, College of Forestry; Wisconsin Department of Natural Resources; John W. Moser, Purdue University; A. B. Johnson, Owens-Illinois Corporation; and Cal Stott, USDA Forest Service (retired).*

[3] *Dietmar Rose and the staff of the Cloquet Forestry Center made the past measurement data available and assisted in the 1976 remeasurement.*

[4] *The data for the four National Forests were provided by The Renewable Resources Evaluation Unit at the North Central Forest Experiment Station.*

[5] *Throughout this paper crown ratio is expressed as a code integer. A crown ratio falling between 1 and 10 percent was coded as 1, 11-20 percent was coded as 2,... and 91-100 percent was coded as 10.*

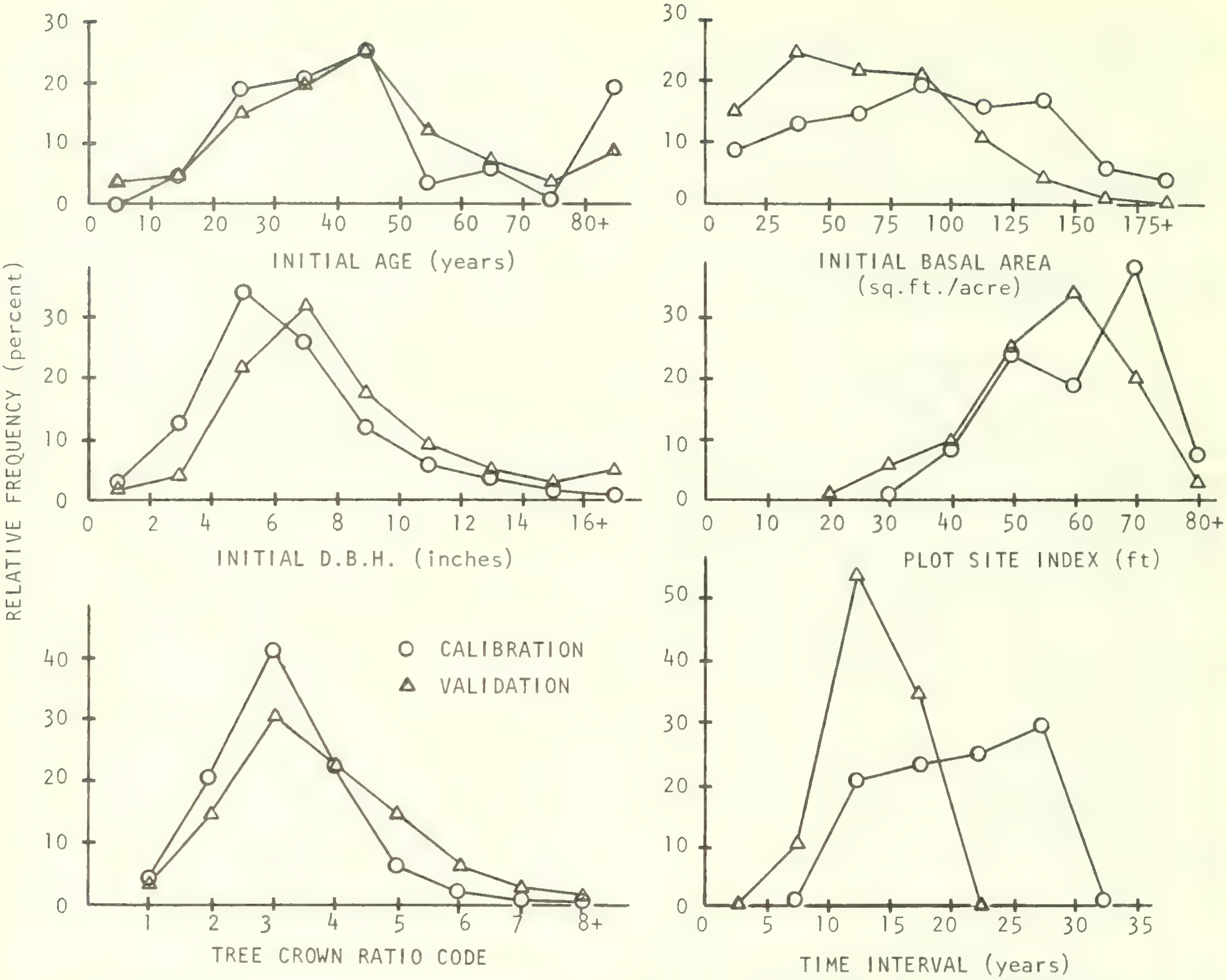

Figure 2.—*Distribution of 293 calibration plots and 822 validation plots in the Lake States by initial conditions for both stand and tree attributes.*

With this equation *an overprediction is a positive error and an underprediction is a negative error.* An accuracy and precision analysis was performed by calculating the mean and standard deviation of the 10 year errors over each class of interest such as forest type, species, property etc. If the predictions were perfect, all errors, and their mean and standard deviation, would be zero. The farther the mean and standard deviation are from zero, the greater the bias and the variability, respectively.

Model Differences

It is important to understand the basic differences in the two models before evaluating them. The original model, GTR49, is a *stand component* model. Each tree list is broken down into a maximum of four species groups and each species group into two size classes. These divisions are called components and hence the name "stand component" model. Each stand component is projected as a whole and later the component's growth is allocated to the individual trees. The current version, STEMS, contains an individual tree model that uses similar equations but deals with individual trees, not components of trees. Belcher *et al.* (1982) presents a detailed description of the model changes in STEMS, but the main differences between the two models are as follows:

(1) Growth potential—the same function and coefficients are used in both growth models but in STEMS they are applied to individual trees not stand components. (Both functions use site index and crown ratio as variables in this equation.)

(2) Site index—GTR49 used a single plot site index for all trees on the plot while in STEMS each species is given a site index. The conversion equations used to predict species site index from the plot site index were provided by Carmean (1979) and Carmean and Vasilevsky (1971).

(3) Crown ratio function—the GTR49 stand component approach has been replaced by an individual tree submodel in STEMS.[6]

(4) Modifier function—the GTR49 stand component submodel has been replaced by an individual tree modifier function[7] that includes an upper limit on the stand basal area.

(5) Interaction—GTR49 attempted to account for interaction between species classes in the modifier function, whereas STEMS does not.

(6) Allocation rule—this function in GTR49 has been removed, and its role is now handled by the modifier function in STEMS.

TEST RESULTS AND DISCUSSION

Model Comparison

In this section we will present a very general overview of the predictive ability of the two models using both the calibration and validation data bases (table 1).

A comparison of the performance of the two models using the calibration data shows both models doing well with little difference between them. However, the STEMS model produces lower standard deviations so it is slightly more precise. The performance of the two models on the calibration data base doesn't reveal any basic mathematical flaw in either model.

The performance of the two models for all the validation properties together shows similar positive mean DBH errors in 10 years. STEMS shows a small NT error whereas GTR49 underpredicts NT an average of 10 trees per acre in 10 years. This underestimation of NT combined with the positive DBH error results in a more accurate estimate of BA for GTR49 than for STEMS, even though STEMS is better on the growth and mortality components separately. In looking at the precision analysis, using the standard deviations, STEMS is slightly more precise than GTR49 for all three key variables—NT, DBH, and BA.

A more detailed analysis also showed that the models performed similarly, but we found three cases in which GTR49 did not predict as well as STEMS. GTR49 overestimated tree DBH's on stands with initial basal areas less than 25 square feet per acre, and it underestimated NT (overestimated mortality) on stands with more than 800 trees per acre or with basal areas of more than 150 square feet per acre. The two problems in the mortality component represent an increase in NT error of about 60 trees per acre, but these conditions only occur on 6 percent of the stands.

Table 1.—*Summary of the mean and standard deviation of the errors in 10 years for GTR49 and STEMS. The errors are evaluated for the attributes of tree d.b.h. (DBH), number of trees per acre (NT), and stand basal area per acre (BA). Errors are computed as predicted attribute minus observed attribute.*

Errors (10 years)	Calibration		Validation											
			All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
	GTR49	STEMS	GTR49	STEMS	GTR49	STEMS	GTR49	STEMS	GTR49	STEMS	GTR49	STEMS	GTR49	STEMS
MEAN														
DBH (inches)	0.02	−0.03	0.13	0.11	0.15	0.06	0.04	0.13	0.06	0.09	0.15	0.09	0.24	0.28
NT (trees/acre)	4	6	−10	2	4	6	−17	16	−33	−18	−11	5	−6	2
BA (sq.ft./acre)	1.3	.6	1.9	3.5	4.7	4.2	−.0	4.7	−2.5	.8	.1	2.2	3.8	5.0
STANDARD DEVIATION														
DBH (inches)	.52	.46	.73	.63	.62	.54	.75	.63	.85	.69	.81	.67	.78	.69
NT (trees/acre)	36	37	81	78	20	20	105	108	103	104	116	100	72	66
BA (sq.ft./acre)	11.6	10.1	14.6	13.4	9.7	9.4	13.7	13.3	15.1	2.4	17.3	14.2	18.7	19.0
NUMBER OF PLOTS	293		822		292		123		145		114		148	
NUMBER OF TREES[1]	7,702		11,182		4,572		1,587		1,775		1,720		1,528	

[1]Values given are for the STEMS model.

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[6] *The crown ratio function is reported in an unpublished manuscript by the senior author.*

[7] *The modifer function is reported in an unpublished manuscript by the senior author.*

One other major problem was found. A 100 year projection of red pine using GTR49 predicted basal areas of more than 450 square feet per acre with no apparent leveling off.

The two models differ in complexity. Schaeffer (1980) states "the simplest model which can be acceptably validated is deemed more suitable than the more complex model." Important in evaluation complexity is the ease in:

(1) calibrating or recalibrating the model,
(2) understanding the various components of the model,
(3) programming the model and understanding the projection program, and
(4) adjusting the model for specific user needs.

In all four of these areas we judged STEMS to be clearly preferable. GTR49 has some complex parts that were hard to calibrate and understand. Considering the factors of performance and model complexity, we recommend STEMS.

A more detailed description of STEMS' performance provides confidence and cautions in its application.

STEMS' Model Performance

Accuracy analysis

Growth component (DBH errors). We will first evaluate the growth component at a broad level by analyzing DBH errors by species for all the validation properties (table 2). Most species on the validation properties have a slight positive bias (overestimate growth). Those species with a mean DBH error of more than 0.30 inches in 10 years are: white spruce (0.32), northern white-cedar (0.37), basswood (0.38), white ash (0.35), and other red oak (0.76). However, all of these species have small mean DBH errors on the calibration data. Taking a weighted average of the validation and calibration totals shows only other red oak (at 0.74) with an error of more than 0.30. Northern white-cedar is the only species with consistently high values on all five validation properties. Diameter growth for all species combined shows a small but consistent overprediction on all five validation properties. In addition, diameter growth on one property, Manistee in lower Michigan, shows a clear overestimation for most species.

Mortality component (NT errors). Information on the mortality component is provided by the NT errors (table 3). Overestimating the number of live trees on a stand indicates that the mortality function is killing too few trees (underestimated mortality).

The four National Forests have variable radius plots with small trees (1 to 5 inch) measured on a 0.01 acre fixed radius plot. If even one of these small trees is assigned the wrong status by the mortality function, the estimated number of live trees per acre would be altered by 100 trees. This is the main reason why the errors were so much larger for these

Table 2.—*Summary of the mean d.b.h. errors (inches) by Lake States species in 10 years using the STEMS model. The number of tree observations appears in parenthesis. Positive values are overpredictions.*

Species	Calibration	Validation					
		All	Cloquet	Chequamegon	Nicolet	Hiawatha	Manistee
Jack pine	– 0.01 (890)	0.13 (1,539)	0.06 (1,109)	0.15 (60)	0.08 (46)	0.40 (162)	0.34 (162)
Red pine	– .04 (3,221)	– .17 (1,360)	– .19 (871)	– .29 (64)	– .08 (69)	– .30 (134)	.00 (222)
White pine	– .11 (148)	– .01 (297)	– .19 (128)	– .02 (36)	– .11 (36)	.13 (73)	.65 (24)
White spruce	– .06 (156)	.32 (148)	– .02 (54)	1.12 (13)	.55 (49)	.22 (32)	—
Balsam fir	– .16 (402)	.11 (556)	.07 (238)	.15 (129)	.14 (114)	.13 (74)	.45 (1)
Black spruce	– .01 (233)	.16 (700)	.17 (556)	.19 (27)	.26 (40)	.02 (75)	.29 (2)
Tamarack	.51 (4)	.03 (227)	.08 (186)	– .24 (21)	– .33 (15)	– .06 (4)	.89 (1)
N. white-cedar	– .02 (236)	.37 (884)	.26 (321)	.47 (104)	.44 (184)	.37 (225)	.55 (50)
Hemlock	.04 (52)	– .13 (296)	—	.06 (46)	– .29 (118)	– .05 (117)	.01 (15)
Black ash	.45 (26)	.16 (163)	.06 (41)	.38 (48)	.03 (29)	.27 (7)	.07 (38)
Red maple	– .01 (152)	– .05 (742)	– .18 (61)	.06 (177)	– .05 (59)	– .13 (243)	.00 (202)
Elm	– .15 (103)	.24 (170)	—	.31 (44)	.13 (110)	.47 (8)	1.17 (8)
Yellow birch	.14 (65)	.00 (232)	.76 (2)	– .02 (81)	.06 (72)	– .07 (65)	– .04 (12)
Basswood	– .07 (231)	.38 (243)	—	.28 (77)	.36 (135)	.08 (5)	.88 (26)
Sugar maple	– .03 (866)	.08 (777)	—	.19 (266)	– .03 (305)	.00 (151)	.45 (55)
White ash	– .08 (193)	.35 (60)	—	.20 (18)	.02 (12)	—	.58 (30)
White oak	– .16 (63)	.08 (244)	—	—	—	—	.08 (244)
Select red oak	– .11 (136)	.15 (246)	– .15 (2)	.20 (111)	– .08 (24)	– .07 (24)	.22 (85)
Other red oak	– .07 (4)	.76 (154)	—	—	—	—	.76 (154)
Hickory	– .23 (54)	—	—	—	—	—	—
Bigtooth aspen	– .17 (5)	– .04 (184)	.32 (25)	– .22 (54)	– .23 (26)	– .18 (30)	.16 (49)
Quaking aspen	.07 (285)	.27 (662)	.33 (252)	.07 (106)	.21 (171)	.37 (93)	.44 (40)
Paper birch	.01 (130)	.10 (1,068)	.16 (726)	– .05 (97)	– .19 (122)	.17 (94)	.18 (29)
All[1]	– .03 (7,702)	.11 (11,182)	.06 (4,572)	.13 (1,587)	.09 (1,775)	.09 (1,720)	.28 (1,528)

[1] Includes all species on the property.

Table 3.—*Summary of the mean number of trees errors (trees/acre) by Lake States forest types in 10 years using the STEMS model. The number of plots appears in parenthesis. Positive values are overpredictions.*

Forest type	Calibration		Validation											
			All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	45	(40)	7	(127)	4	(79)	14	(7)	72	(6)	15	(20)	−19	(15)
Red pine	3	(89)	6	(85)	1	(49)	60	(6)	−24	(4)	−1	(11)	12	(15)
White pine	−1	(12)	1	(13)	16	(6)	0	(2)	−44	(2)	1	(3)	—	
White spruce	−56	(2)	2	(10)	5	(4)	0	(1)	2	(4)	−3	(1)	—	
Balsam fir	7	(3)	31	(51)	16	(23)	38	(14)	−4	(8)	121	(6)	—	
Black spruce	15	(6)	15	(40)	19	(29)	−182	(2)	83	(3)	26	(6)	—	
Tamarack	—		−17	(23)	−8	(19)	−2	(2)	−116	(2)	—		—	
N. white-cedar	−32	(4)	−23	(47)	15	(14)	−18	(8)	−55	(9)	−59	(14)	89	(2)
Hemlock	−3	(2)	1	(7)	—		—		9	(4)	−9	(3)	—	
Lowland hdwds.	15	(6)	32	(30)	21	(3)	75	(5)	15	(2)	−139	(1)	33	(19)
N. hardwoods	−3	(76)	−2	(135)	—		14	(40)	−20	(49)	1	(28)	9	(18)
White oak	−3	(3)	−3	(15)	—		—		—		—		−3	(15)
Northern red oak	2	(10)	68	(15)	—		116	(4)	95	(1)	58	(2)	44	(8)
Oak-pine	—		−33	(10)	—		—		—		−16	(1)	−35	(9)
Oak-hickory	1	(6)	−36	(35)	—		−300	(1)	—		—		−28	(34)
Aspen	2	(31)	−4	(121)	5	(30)	26	(23)	−38	(42)	−6	(14)	31	(12)
Paper birch	5	(3)	5	(58)	3	(36)	−21	(8)	8	(9)	76	(4)	2	(1)
All	6	(293)	2	(822)	6	(292)	16	(123)	−18	(145)	5	(114)	2	(148)

four properties than they were for either the calibration data or Cloquet. If the mortality function is accurate, these deviations should average out over all properties. This can be evaluated by checking the "all validation" results.

Five forest types are in error by more than 30 trees in 10 years—balsam fir (31), lowland hardwoods (32), oak-pine (-33), oak-hickory (-36), and northern red oak (68). Limited data were originally available to calibrate these particular forest types, and note that three of them include the oak species. When looking at the individual property results, northern red oak is clearly the worst. Even though jack pine had a large error (45) on the calibration data, it did well on the validation data.

Overall model (BA errors). The BA errors provide information on the complete model, i.e., how well the growth and mortality components work together (table 4). For all the validation properties, the forest types with BA errors more than 9 square feet in 10 years are balsam fir (9.5), black spruce (9.4), northern white-cedar (9.1), and lowland hardwoods (19.6). The marked overestimation of lowland hardwood species is also evident on the calibration data. In all

Table 4.—*Summary of the mean basal area errors (sq. ft./acre) by Lake States forest types in 10 years using the STEMS model. The number of plots appears in parenthesis. Positive values are overpredictions.*

Forest type	Calibration		Validation											
			All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	6.9	(40)	2.7	(127)	2.0	(79)	4.4	(7)	5.2	(6)	4.0	(20)	2.9	(15)
Red pine	−.9	(89)	−.9	(85)	−.2	(49)	5.0	(6)	−5.6	(4)	−8.0	(11)	.8	(15)
White pine	−3.3	(12)	.4	(13)	3.5	(6)	−.7	(2)	−7.1	(2)	−.0	(3)	—	
White spruce	−9.5	(2)	.5	(10)	4.3	(4)	−2.3	(1)	−.4	(4)	−7.9	(1)	—	
Balsam fir	7.7	(3)	9.5	(51)	10.8	(23)	4.2	(14)	5.5	(8)	22.1	(6)	—	
Black spruce	6.7	(6)	9.4	(40)	9.3	(29)	−1.8	(2)	25.4	(3)	5.9	(6)	—	
Tamarack	—		.0	(23)	1.4	(19)	1.0	(2)	−14.0	(2)	—		—	
N. white-cedar	−8.9	(4)	9.1	(47)	11.9	(14)	5.1	(8)	5.3	(9)	7.3	(14)	35.4	(2)
Hemlock	−6.9	(2)	−8.2	(7)	—		—		−8.5	(4)	−7.7	(3)	—	
Lowland hdwds.	10.3	(6)	19.6	(30)	10.2	(3)	22.0	(5)	6.0	(2)	−10.6	(1)	23.5	(19)
N. hardwoods	−.4	(76)	3.4	(135)	—		4.9	(40)	.7	(49)	−1.5	(28)	15.3	(18)
White oak	−3.7	(3)	−.9	(15)	—		—		—		—		−.9	(15)
Northern red oak	5.2	(10)	7.4	(15)	—		10.1	(4)	25.0	(1)	1.8	(2)	5.3	(8)
Oak-pine			−2.5	(10)	—		—		—		−22.1	(1)	−.3	(9)
Oak-hickory	3.4	(6)	−8.1	(35)	—		−15.0	(1)	—		—		−7.8	(34)
Aspen	−2.6	(31)	3.1	(121)	6.5	(30)	4.0	(23)	−1.2	(42)	1.2	(14)	10.2	(12)
Paper birch	5.9	(3)	3.3	(58)	3.3	(36)	−.3	(8)	−.7	(9)	17.9	(4)	9.2	(1)
All	.6	(293)	3.5	(822)	4.2	(292)	4.7	(123)	.8	(145)	2.2	(114)	5.0	(148)

problem cases mentioned above limited data were available to calibrate the model.

Error patterns. Error patterns in the growth component for the three key variables—DBH, NT, and BA—over various initial conditions shows that the problem areas in the validation data generally occur where there are few observations (figs. 3 and 4). Errors in these classes should cause little difficulty unless projections are to be made in these extreme ranges. Because much more variability exists in classes with few observations, caution needs to be exercised when emphasizing these trends.

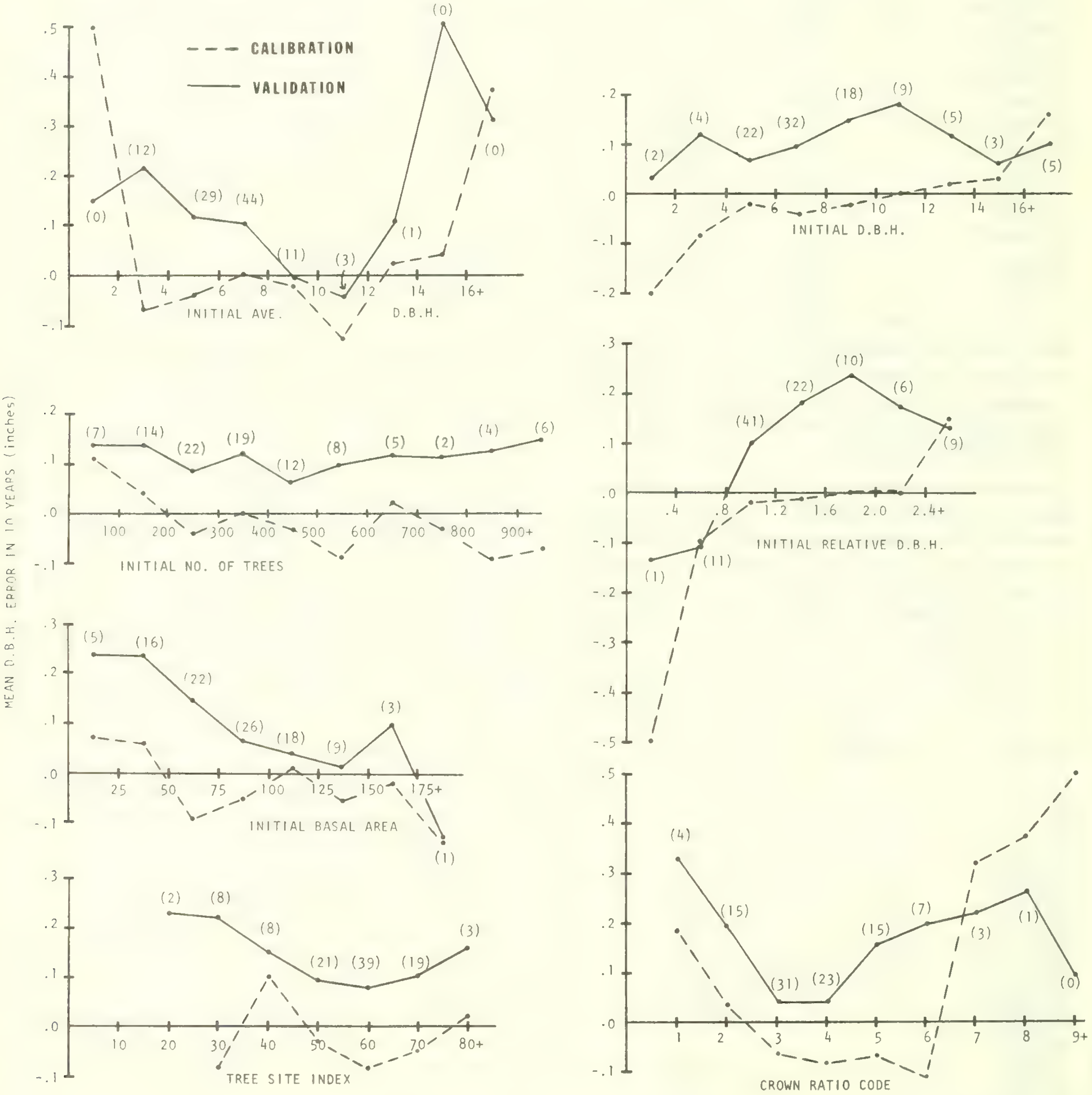

Figure 3.—*The mean d.b.h. errors in 10 years plotted against selected initial tree and stand conditions. The percent of the observations in each class for the validation data is given in parentheses.*

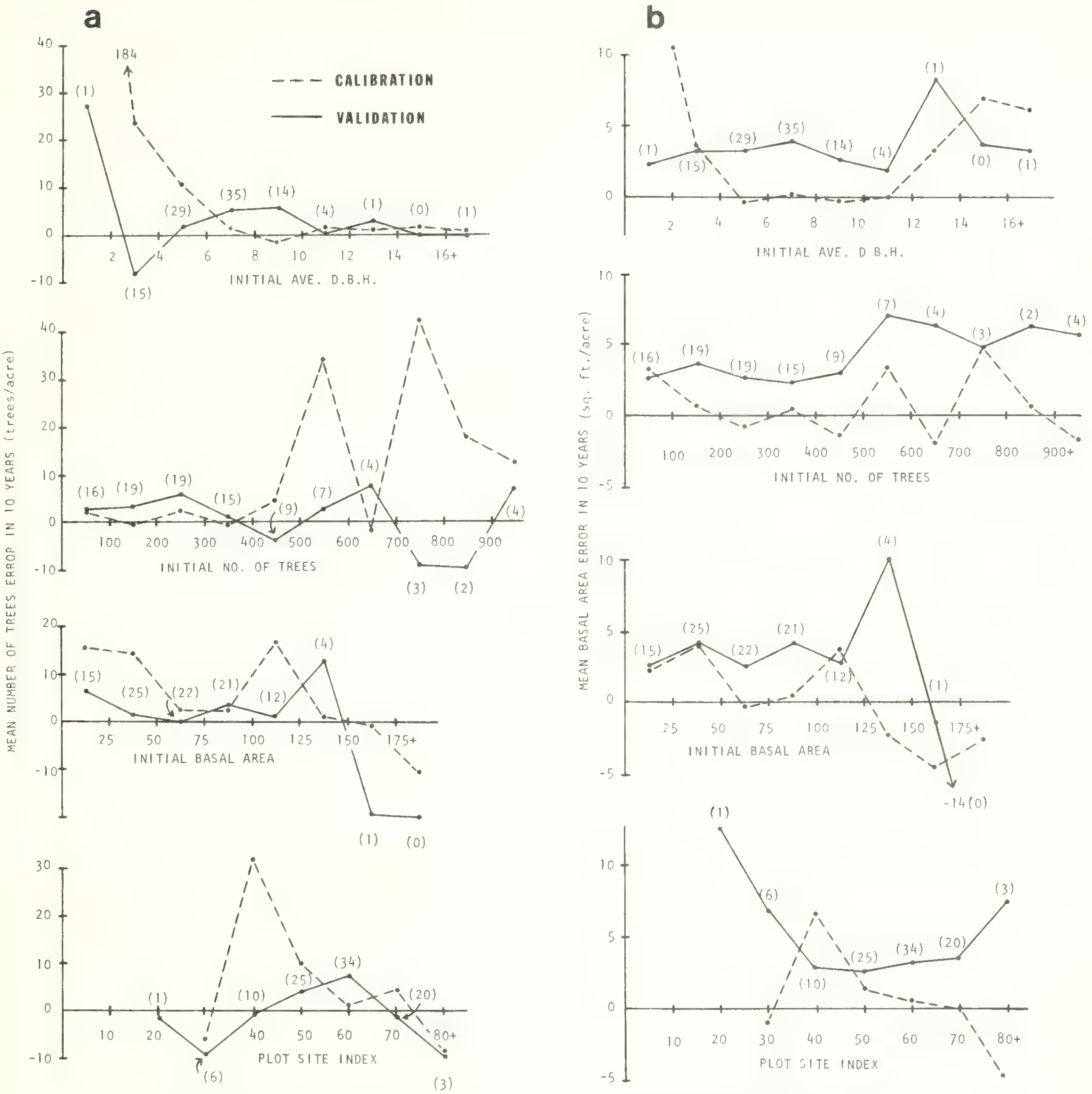

Figure 4.—*The (a) mean number of trees errors and (b) the mean basal area errors in 10 years plotted against selected initial stand conditions. The percent of the plots in each class for the validation data is given in parenthesis.*

It would seem logical to include age in the list of initial conditions evaluated. However, age is not always an accurate variable. For example, when a plot has been clearcut, the new age becomes zero even though a few undesirable old trees may still remain. Thus a plot listed as 5 years old could have an average diameter of 12 inches. Consequently we have not included age. Many of the same results can be obtained by studying average diameter trends.

Some potential problem areas surfaced on both the calibration and validation data. One such area is the excessive growth put on trees in stands with large initial average diameters and to a lesser degree on trees in stands with very low average diameters (fig. 3). This evidence is based on few trees. On the initial basal area graph, there is a very slight trend to overgrow low basal area stands on the calibration data. This trend is clearly magnified on the validation data. (Recall that we had much more data in the low basal area range on the validation properties (fig. 2).) For tree site index a noticeable curvilinear trend appears in the errors for the validation data, although, because of the distribution of the data, the model performs well for 79 percent of the trees. This same trend also appears in the calibration data, but at a mean DBH error of 0.2 inches lower. Likewise, a curvilinear trend similar to that for tree site index appears for crown ratio code. Tree site index and crown ratio code are handled in the same term of the growth potential function so these results indicate that the functional form chosen does not adequately describe the biological mechanisms at work.

The initial relative d.b.h. (relative d.b.h. = d.b.h./average d.b.h.) for the validation properties shows a clear increasing trend with a marked overgrowth of overstory trees (relative d.b.h. greater than 1). This trend is bothersome because even a small overgrowth will be magnified with longer projections. The trend tapers off for very large relative values and so becomes somewhat self-correcting. Because this trend is not evident for the same class of trees on the calibration data, the problem is likely due to a difference between the data bases. "Extreme" understory trees (i.e., relative d.b.h. 0.4 or less) are sharply underestimated on the calibration data and somewhat underestimated on the validation data. This would account for the slight underestimation of DBH for trees with small initial diameters.

The problem areas are due to difficulty with the form of the equations used to estimate the various growth components or to a limited amount of data to calibrate against. The main problems indicate possible model weaknesses in how the crown ratio and site index are incorporated into the growth potential and how competition (as measured by basal area and possibly relative diameter) is handled in the modifier function. However, the various parts of the growth component are so interrelated that correcting one problem often introduces difficulties with another part of the model. Those cases where difficulties are clearly evident occur from 10 to 20 percent of the time, often under somewhat extreme conditions.

No trends emerge from the error patterns for the mortality component when evaluating both the validation and calibration data (fig. 4a). However, NT variability increases for stands with low average d.b.h. and with high number of trees. Both results are logical in that a greater number of trees will magnify NT errors.

Finally, performance for the entire model, as measured by the mean BA error (fig. 4b), shows no clear trends. However, errors in the growth and mortality components may cancel each other or combine to heighten an already noticeable trend. We investigated several examples of error effects and found that a 10 percent error in DBH produced roughly a 20 percent error in BA, whereas a 10 percent error in NT produced only a 10 percent error in BA. Thus accuracy in predicting diameter growth is twice as important as accuracy in predicting the mortality component. In evaluating the data, trends evident in the growth component have been largely muted by the mortality effect. The one exception is the site index trend for the validation properties, which seems even more pronounced.

DBH error by diameter class. Further analysis of the growth component is provided through evaluation of diameter errors for initial diameter classes (table 5). For many species the model estimates tree growth well for the lower diameter ranges but overpredicts growth for the middle diameter classes. This overprediction is smaller for the few larger trees in the data base. When the results are graphed, a few species show a marked relation between diameter and diameter prediction error. We found clear increasing trends for white pine, northern white-cedar, and black ash and strong decreasing trends for bigtooth aspen and quaking aspen. The red pine equation consistently underpredicted growth on trees less than 14 inches d.b.h.

Species mortality rates. The mortality component can be evaluated as a tree attribute in addition to the NT evaluation as a stand attribute. As a tree attribute, we calculated the observed and predicted annual mortality rates for each species based on the number of trees that survive through an observation interval and the length of that interval (table 6).

The observed mortality rates vary widely from species to species. For example, the observed annual mortality rate for quaking aspen is more than 30 times as great as that for red pine. More important, however, is how close the predicted rate is to the observed rate. In many cases it is very close—red pine, hemlock, red maple, and yellow birch to name a few. Several, however, are not close—balsam fir, black spruce, elm, tamarack, black ash, and other red oaks. Because the last three of these were calibrated from limited data, the function coefficients may not be reliable. The remaining three—balsam fir, black spruce, and elm—are subjects of insect or disease outbreaks. Balsam fir is defoliated by the

Table 5.—*Mean d.b.h. errors (inches) in 10 years by species and diameter class for all validation data sources. Positive values are overpredictions.*

Species	No. of trees[1]	Diameter class (inches) 0-3+	4-5+	6-7+	8-9+	10-11+	12-13+	14-15+	16+	All classes	Mean d.b.h. growth in 10 years
Jack pine	1,539	−0.12	0.05	0.08	0.21	0.27	0.21	0.14	−0.65	0.13	1.01
Red pine	1,360	−.33	−.12	−.20	−.44	−.43	−.14	.01	.45	−.17	1.72
White pine	297	−1.00	−.42	−.38	−.11	.20	.49	.12	.17	−.01	1.78
White spruce	148	.37	.08	.27	.43	.61	.46	.49	.55	.32	1.65
Balsam fir	556	−.05	.02	.17	.33	.31	.34	.41	—	.11	1.13
Black spruce	700	.03	.15	.18	.22	.32	—	−2.80	—	.16	.73
Tamarack	227	−.36	.02	−.02	.05	.47	−.06	.53	—	.03	.67
N. white-cedar	884	.09	.19	.31	.51	.65	.82	.64	.52	.37	.82
Hemlock	296	−.17	−.22	−.04	−.12	.06	−.29	−.14	−.15	−.13	.94
Black ash	163	−.35	−.02	.15	.35	.54	.51	30	.27	.16	.61
Red maple	742	.29	−.01	−.07	−.06	−.15	−.20	−.51	−.29	−.05	1.20
Elm	170	−.19	−.01	.20	.43	.28	.05	.71	.36	.24	1.39
Yellow birch	232	.04	.09	.02	−.21	.20	.10	−.03	−.04	−.00	.92
Basswood	243	.50	.70	.38	.29	.26	.20	.38	.41	.38	1.31
Sugar maple	777	.24	.09	.06	.10	.21	.06	.12	−.23	.08	1.20
White oak	244	−.12	.10	.10	.19	11	.09	.02	−.05	.08	.89
Select red oak	246	.25	.30	.17	.05	.14	−.19	−.08	.31	.15	1.46
Other red oak	154	—	.96	.54	.95	.88	.83	.84	.50	.76	1.12
Bigtooth aspen	184	.34	.27	.11	−.15	−.37	−.71	−.86	−.96	−.04	1.55
Quaking aspen	662	−.13	.24	.38	.33	.16	−.10	−.20	−.73	.27	1.45
Paper birch	1,068	−.14	.02	.11	.21	.15	.34	.25	.03	.10	1.07
All[2]	11,182	.09	.07	.10	.15	.18	.12	.06	.10	.11	1.16
Percent trees in diameter class		6	22	32	18	9	5	3	5	100	

[1] Species with fewer than 100 observations have been omitted.

[2] Includes species with fewer than 100 observations.

Table 6.—*Predicted and observed annual tree mortality rates by Lake States species for all validation properties (includes all trees that were initially alive and not cut).*

Species	No. of trees	Annual tree mortality rate Predicted	Observed
		Percent	
Jack pine	2,336	1.2	1.6
Red pine	1,397	.1	.1
White pine	363	.3	1.1
White spruce	187	1.2	.6
Balsam fir	1,092	1.4	3.2
Black spruce	1,024	.6	1.8
Tamarack	370	2.5	.6
N. white-cedar	987	.3	.6
Hemlock	323	.3	.5
Black ash	254	.9	2.4
Red maple	852	.7	.6
Elm	293	1.2	3.8
Yellow birch	321	1.6	1.6
Basswood	303	1.2	1.0
Sugar maple	946	1.4	.7
White ash	65	.1	.6
White oak	274	.4	.7
Select red oak	273	.6	.5
Other red oak	312	5.8	.8
Bigtooth aspen	270	1.7	1.5
Quaking aspen	1,468	2.5	3.3
Paper birch	1,191	.2	.5
All[1]	15,240	1.1	1.4

[1] Includes all species on the property.

spruce budworm, *Choristoneura fumiferana;* black spruce is a host for dwarf mistletoe, *Arceuthobium pusillum;* and elm is killed by Dutch elm disease caused by the fungus *Ceratocystis ulmi* (USDA Forest Service 1979b). None of these damaging agents were present at high levels on the calibration locations during the measurement periods involved. In several of the validation areas, however, these agents were present at high levels.

Balsam fir mortality is underpredicted on all the validation properties. For all four properties where balsam fir is an important component, spruce budworm was present in the area during the measurement period (USDA Forest Service 1962, 1968, 1971, 1977). Therefore, spruce budworm may partially account for the poor performance of the balsam fir mortality predictions.

Most of the black spruce data is from the Cloquet forest. However, dwarf mistletoe has not caused significant mortality on the Cloquet forest (D. W. French and F. A. Baker, personal communications). So mistletoe does not account for the discrepancy.

Predicted and observed elm mortality rates are close for all sources except the Manistee National Forest. There, the observed mortality rate was 18 percent as compared to a predicted rate of only 1 percent. Dutch elm disease was responsible for large elm losses in lower Michigan in 1962 and by 1971 most of the elms were dead (USDA Forest Service 1962, 1972). Yet it wasn't until near the end of the measurement period that the disease was common in northern Wisconsin and upper Michigan (USDA Forest Service 1977). This helps to explain the contrast between Manistee and the other areas.

Precision analysis

In this section we will discuss some general aspects of variablity in the model evaluation process. The first analysis is a comparison of the actual and predicted distribution for the three test variables: DBH, NT, and BA (fig. 5). All three test variables agree closely between the predicted and observed distributions with perhaps a bit more discrepancy in the basal area results, which is to be expected. The closeness of these two distributions is in part a function of the interval length. The longer the projections, the greater the discrepancies no matter how well the model predicts. These results are standardized to 10 years for all validation properties combined.

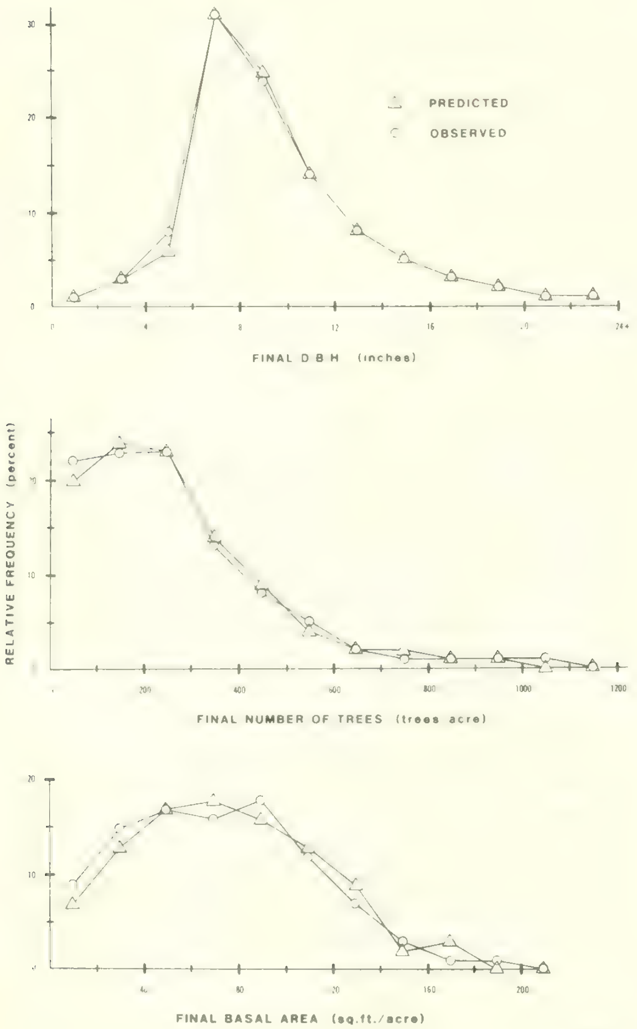

Figure 5.—*A comparison of the frequency distributions of the predicted and observed values for tree d.b.h., number of trees, and stand basal area, standardized to 10 years. All validation sources are included.*

The second analysis of variability is the cumulative frequency of the errors for each test variable (fig. 6). Differences are shown between predicted and observed values for DBH, NT, and BA standardized to 10 years for all validation properties.

The graphed results can be viewed two ways. One is to say that 68 percent of the tree diameter observations will have an error of between -0.35 and 0.55 inches in 10 years (or, 95 percent are between -1.2 and 1.2 inches). The other is to know what percent of the trees had predicted DBH values within, for example 0.5 inch of the observed DBH. Viewed in this manner, 71 percent of the trees (82 percent–11 percent) had predicted diameters within 0.5 inches of the true value, 88 percent of the plots (93 percent–5 percent) had predicted NT within 100 trees per acre, and 68 percent of the plots (78 percent–10 percent) had BA values predicted to within 10 square feet.

A third precision analysis, based on the Cloquet Experimental Forests, is included in the time analysis discussion below.

Time analysis

Short-term effect. Prediction errors can be expected to increase as the length of the projection interval increases. We examined these error trends to determine their magnitude and form.

We used the data from the Cloquet validation for the time analysis because it was the only one that was remeasured more than once after the initial measurement. It was remeasured 5, 10, and 17 years after the initial measurement. The analysis was done at the stand level using BA errors, which provide a good overview of the entire model performance on a variable of interest to most users. On the average, we found that errors increase as the projection interval increases and variability of the errors increases as well (fig. 7).

An analysis of accuracy for all types combined shows that BA is overestimated on the average by

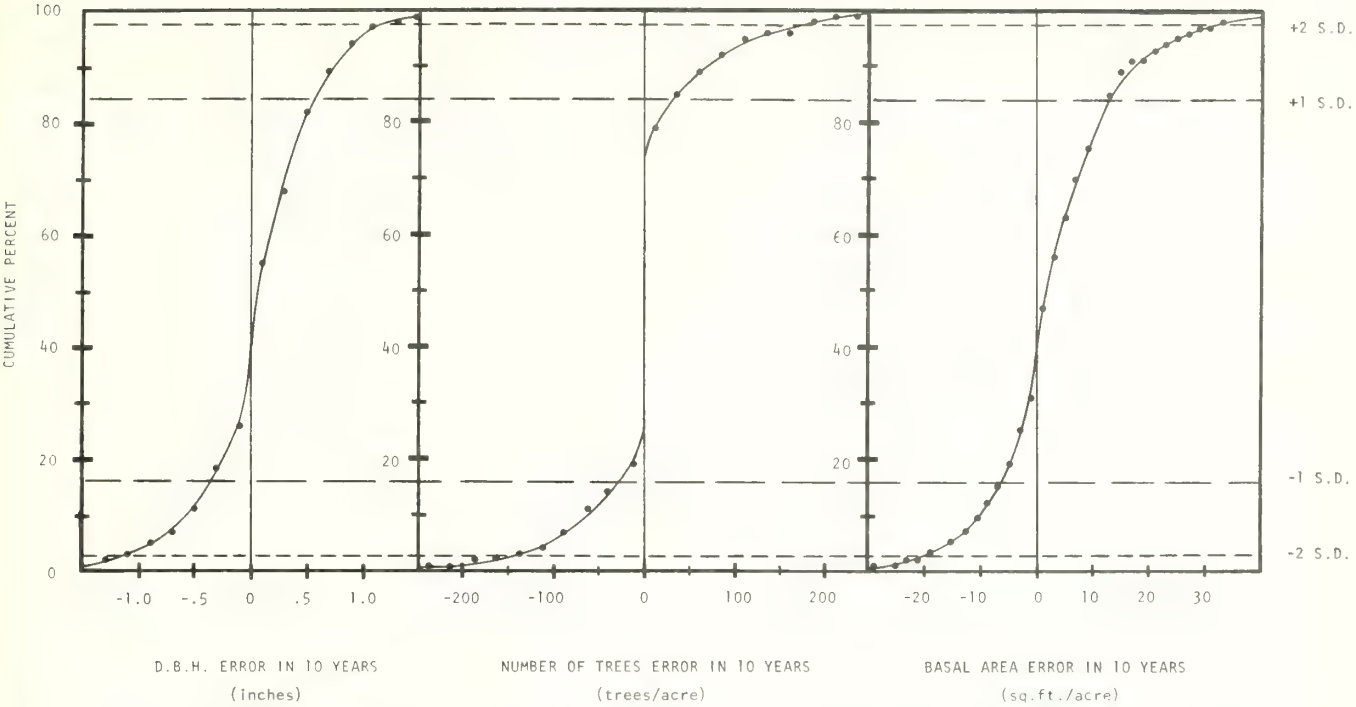

Figure 6.—*Cumulative frequency of 10 year errors in predicting tree d.b.h., number of trees, and stand basal area for all validation sources. The error equals the predicted attribute minus the observed attribute. Lines representing ±1 and ±2 standard deviations have been added.*

7 square feet in 17 years. However, some types (balsam fir, black spruce, northern white-cedar, and lowland hardwoods) were overestimated by as much as 16 to 20 square feet. These types account for 24 percent of all the plots.

The precision results for all types show the standard deviation of the BA error to be 16 square feet in 17 years. Stated in slightly different terms, 68 percent of the basal area errors fall between -6 and 13 square feet after 10 years and between -9 and 23 square feet after 17 years. When the mean error and/or standard deviation are large, fairly high BA errors may be encountered (e.g., balsam fir, black spruce, and quaking aspen types). Atypical patterns were found for white spruce and lowland hardwoods.

But we still need to assess the assumption of linear decay of errors made when the time adjustment was introduced. If the annual rate of decay is constant, the lines should be linear through the origin. When *all* types are combined, the linear assumption holds up to 10 years. Adjusting the 17 year values to 10 years would usually result in a slight overestimation of BA error at 10 years because the pattern is slightly convex. Further analysis, not given here, revealed that NT trends were more convex. Therefore, on the average, the stand level results when adjusted to 10 years will make STEMS appear worse than it is. However, at the tree level combining all species, the DBH trends were nearly linear.

A few of the individual forest types on Cloquet had noticeable nonlinear trends (fig. 7). But the only clear cases in which the error would be *underestimated* are white pine (6 plots), white spruce (4), and balsam fir (23). The remaining four validation properties had measurement lengths of 9 to 11 years. Adjusting these results to 10 years presents no problem. This supports our adjustment approach, especially on the validation properties.

Long-term effect. An evaluation of long-term projections, as used when studying forest succession, becomes more difficult because there are no existing remeasured plots for comparison. One evaluation approach is to compare the results of the projection with expectations based on professional judgment. This is often sufficient to detect gross errors in the model. Another approach is to compare the results with published yield tables. However, there are problems with this approach: (1) the yields are based on summaries of different stands at specific ages; (2) the averages derived from these stands represent the development of a *theoretical* stand; (3) the results do not represent an actual growth series; and (4) it is difficult to de-

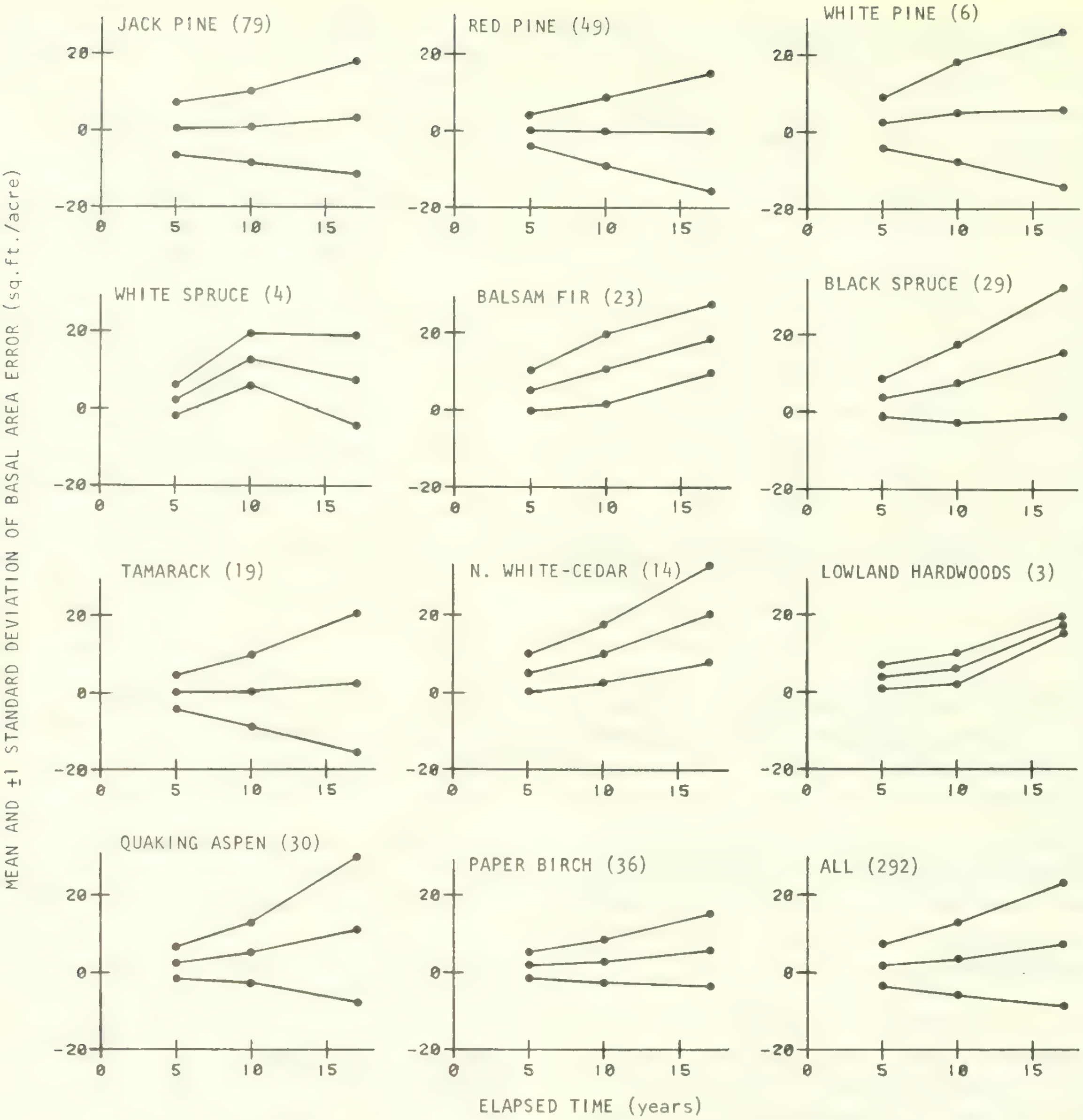

Figure 7.—*Pattern of mean and standard deviation of basal area error by forest type on the Cloquet Experimental Forest, Minnesota. Standard deviations are shown by the outer lines. The number of plots for each forest type is given in parentheses.*

velop an appropriate initial tree list because the yield tables do not specify such things as species composition and diameter distributions. Despite these problems, we used a combination of scientific judgment and published yield tables to evaluate the model's long-term predictive capabilities.

We made two long-term projections on pure stands—a conifer (red pine) and a hardwood (quaking aspen) (fig. 8). Both stands, site index 60, were begun at age 20 and were projected for 100 years. The red pine stand projections showed good agreement with the basal area table of Stiell and Berry (1973) at age 50, the extent of the published table. For quaking aspen, the greatest difference between the projection and the yield table values of Brown and Gevorkiantz (1934) was 18 square feet per acre at age 50. Both projections followed the general trends indicated from the yield tables and continued on in a reasonable manner. Although this is only a cursory examination of the model's long-term projections, it suggests that the model does not produce gross errors for red pine and aspen.

Data base differences

The calibration and validation data bases have one very important difference. The calibration data came from research plots so the coefficients were

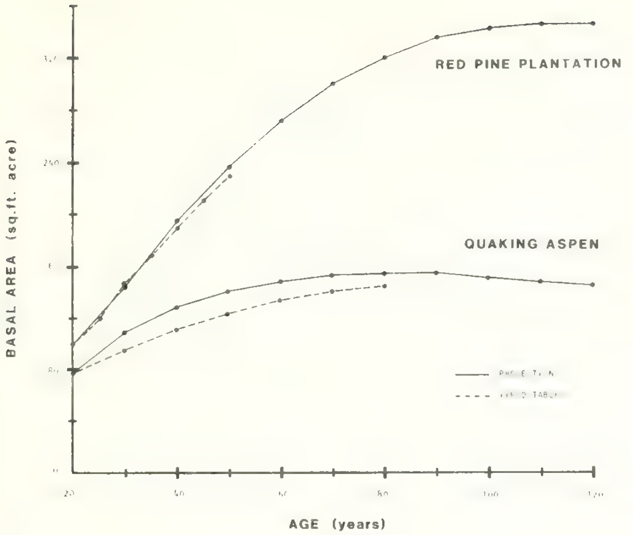

Figure 8.—*Comparison of long-term STEMS projections with published yield table results for red pine and quaking aspen stands on a site index of 60.*

developed primarily from plots where uniform spacing was the goal. However, the validation data came from general plots so the model was applied on plots where spacing may be far from ideal. Unequal spacing may reduce production below the optimum found with uniform spacing. The expected results, when projecting general stands, would be to overpredict growth. Certainly, diameter growth is consistently overestimated on all validation properties (table 2). These results agree with those of Bruce (1977).

Also the range of conditions differs between the calibration and validation data bases. The data base used to calibrate the model contained fewer low basal area plots and more high basal area plots than the validation properties (fig. 2). Our results (fig. 3) show that the model overgrows low basal area stands. Therefore, if this type of stand is predominant, the model would perform poorly. This is also probably a contributing factor to the overprediction on the validation properties.

Crown ratio analysis

Crown ratio, an important variable in the growth potential, had been measured on each tree used in the evaluation. We analyzed the growth and mortality components of the models without introducing errors from crown ratio estimates. Therefore, we will present a separate validation of the crown ratio function for those cases in which crown ratio would be estimated in STEMS, i.e. not recorded when trees were measured. Because all trees in the validation data had a known crown ratio, we used the crown ratio function to predict the crown ratio of each tree and then we evaluated the resulting prediction errors.

The overprediction of crown ratio for all species combined is 0.78, with individual species ranging from 0.31 to 1.30, except for red pine at -0.07 (table 7). Plotting the mean crown ratio code errors over stand basal area also provides evidence of a marked basal area trend in which the errors decrease as basal area increases (fig. 9).

The crown ratio function in STEMS was calibrated using Forest Survey inventory data from Wisconsin and northern Minnesota[6] that included a wide range of stand basal area and diameter conditions. The crown ratio codes observed from the inventory data tended to be as much as 1 unit higher than those observed on the calibration data. We found no apparent cause for this discrepancy, but obviously it has contributed to the overestimates of crown ratio.

How much effect do these overprediction errors have on the estimated growth? One National Forest, Chequamegon, was also projected assuming unknown crown ratios. The results showed that when the crown ratio function is used to estimate the crown ratios, the mean DBH error increased from 0.13 to 0.25 inches in 10 years and the mean BA error increased from 4.7 to 8.1 square feet per acre in 10 years.

Table 7.—*Summary of crown ratio function test showing mean crown ratio code errors by Lake States species for all trees on the validation properties.*

Species	No. of trees	Mean crown ratio code error
Jack pine	1,906	1.07
Red pine	1,626	−.07
White pine	368	1.07
White spruce	257	.79
Balsam fir	988	1.10
Black spruce	957	1.26
Tamarack	385	1.02
N. white-cedar	1,002	.44
Hemlock	306	.31
Red maple	837	1.09
Elm	194	1.01
Yellow birch	272	1.02
Basswood	274	1.30
Sugar maple	878	1.18
White ash	61	1.30
White oak	255	.52
Select red oak	259	.57
Other red oak	286	.44
Bigtooth aspen	235	.94
Quaking aspen	1,140	.94
Paper birch	1,277	.31
Total	13,763	.78

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[6] *See page 7.*

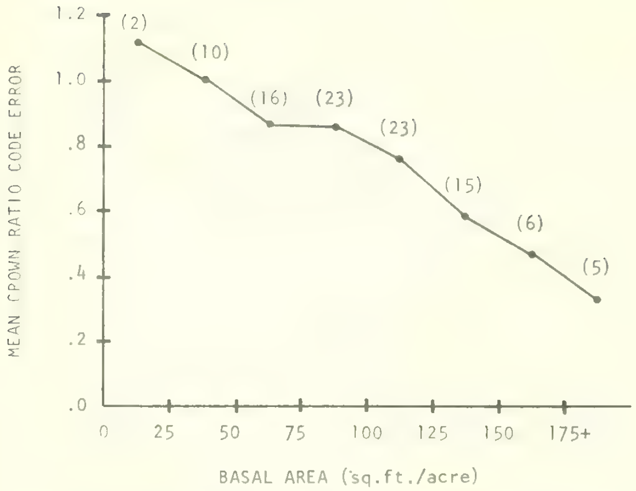

Figure 9.—*Mean crown ratio code errors plotted against the stand basal area for all trees on the validation properties. The percent of the observations in each class is given in parentheses.*

It is possible that crown ratios vary more by location than other variables. Therefore, users may have to test the predicted crown ratio values against known values from the location of interest to determine if an adjustment is needed. At present, if the STEMS model is used to grow trees with unknown crown ratios, it will probably overpredict crown ratios and hence overgrow tree diameters.

SUMMARY

A projection system is evaluated by analyzing its capabilities to predict behavior in the real world. In this paper, we evaluated the STEMS projection system by analyzing the differences (or errors) between the predicted and observed values on three key variables—tree d.b.h. (DBH), number of trees per acre (NT), and stand basal area per acre (BA). Performance of the growth component was measured by DBH errors, the mortality component by NT errors, and the system as a whole by BA errors. Many of the basic tests were performed on two data sets: (1) a systematic sample of every fifth plot from the calibration data base, and (2) an independent data base comprised of five different sources located in Minnesota, Wisconsin, and Michigan.

Initially, we evaluated two growth models—the original GTR49 model and the current STEMS model. The results indicate the two models are similar in many ways. However, the STEMS model (1) is slightly more precise; (2) performs slightly better than the GTR49 model in three areas as judged by error patterns; (3) does not grossly overpredict yields on long-term projections as the GTR49 model did on some species; and (4) is simpler to calibrate, understand, and use.

Included in the tests on STEMS are analyses of accuracy, precision, and time effect. The important findings and observations are summarized below, including an attempt to identify the major areas of weakness of the STEMS model.

1. Both models predicted growth and mortality well on the calibration data base. Therefore, we have no reason to suspect any basic mathematical flaw in either model.
2. STEMS did reasonably well projecting plots from the five independent properties comprising the validation data source. The *major* problem areas involved predicting diameter growth for other red oak, mortality for northern red oak, and stand basal area for lowland hardwoods. In most of these cases, few trees were available to use for calibration.
3. In an evaluation of the error patterns for the three test variables over a wide range of initial conditions, we found that the STEMS model overgrows trees under the following conditions:
   (a) when basal area of the stands are low—especially below 50 square feet per acre,
   (b) when tree site index is 30 and below,
   (c) when crown ratio codes are 2 and below, and
   (d) when the relative d.b.h. of overstory trees is between 1.2 and 2.2.

   The problems listed in (b) and (c) indicate possible model weaknesses in the growth potential and those in (a) and (d) with competition as it is handled in the modifier function.

4. Tree diameter errors given by species and initial diameter classes generally show that the model predicts diameter growth well for the lower diameter classes but overpredicts growth for the middle diameter classes. This overprediction decreases for the few larger trees in the data base.
5. The problem with underpredicting mortality on balsam fir and elm on the validation properties may be due to outbreaks of spruce budworm and to Dutch elm disease. These damaging agents were not present at high levels on the calibration locations during the measurement periods involved.
6. In general, very little error was introduced in the validation results by standardizing the time and if errors do result, they usually will be conservative. This approach to model testing allows us to use and compare data with different measurement intervals. But standardization of the time is only valid if the decay of errors is approximately linear for the measurement length used.

In the Cloquet example given, most species showed fairly linear trends through 17 years. In those cases where the pattern was slightly convex, adjusting to 10 years results in a slight overestimation of the error. The other four validation properties had measurement intervals of 9 to 11 years, so we had no problem with those data.

7. The STEMS model was tested using long-term projections for two species. The projections seemed reasonable when compared with results from yield tables.
8. Diameter growth was consistently overpredicted on all validation properties. We are not so much concerned with the magnitude of the error as with the possibility of a consistent positive bias. Is there a possible explanation for these results? One possible explanation is that research plots were used to calibrate the model. Growth on these plots would be greater because they are uniformly spaced and mortality would be lower because of the cutting procedures used. Another possible explanation is that the validation properties had a large proportion of low basal area plots. These plots were consistently overgrown, which probably contributed to the overprediction.
9. Finally, when the crown ratio function was used to estimate missing crown ratio codes, it overpredicted them by an average of 0.78 units. This will ultimately overpredict the diameter growth as well. If crown ratio is missing, an adjustment factor may be necessary to correct for this bias in the function.

In conclusion, on the validation properties the STEMS model overgrows trees on the average by 0.11 inches in 10 years. On 71 percent of these trees it predicted the diameter to within 0.5 inches of the observed diameter after 10 years growth. Likewise, the model overestimated stand basal area on the average by 3.5 square feet per acre after 10 years growth and on 70 percent of these plots it predicted the basal area to within 10 square feet per acre of the true value.

This paper provides the users of the STEMS projection system with extensive quantitative information about how well the model predicts and also highlights possible problem areas. Nevertheless, it is the user's responsibility to determine the model's usefulness for his particular application. His decision needs to be based on an in-depth examination of all the evidence. Careful scrutiny of the tables and figures is important. Furthermore, we encourage users to test the model on their own data whenever possible. This will help them determine if the model will meet their needs, or what parts of the model may be suspect, before making a major commitment of time and money.

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STEMS (Stand and Tree Evaluation and Modeling System) is a tree growth projection system. This paper (1) compares the performance of the current version of STEMS developed for the Lake States with that of the original model and (2) reports the results of an analysis of the current model over a wide range of conditions and identifies its main strengths and weaknesses.

KEY WORDS: Validation, testing, growth model, Lake States species, verification.

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Diversity of Vertebrates in Wildlife Water-Impoundments on the Chippewa National Forest

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John R. Probst, Donald Rakstad, and Kathy Brosdahl

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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DIVERSITY OF VERTEBRATES IN WILDLIFE WATER-IMPOUNDMENTS ON THE CHIPPEWA NATIONAL FOREST

John R. Probst, *Research Biologist,*
Donald Rakstad, *Biological Technician,*
and **Kathy Brosdahl,** *Biological Aid*

Wetlands cover 154,000 acres of the Chippewa National Forest, or 24 percent of its surface area. In 1965, only about one-fourth of this area was at or near its full potential for waterfowl production (Mathisen 1965). The management plan called for improving about 50,000 acres of the sub-optimum wetland by burning, blasting, and constructing artificial impoundments and nesting sites.

Since that time, 47 low-head dams have been constructed to flood the less productive sedge meadows and shrub swamps to create habitats more attractive to most species of wildlife in the area. Most of these structures reclaim abandoned beaver flowages as well. In addition, more than 5,000 potholes have been excavated and more than 7,000 nesting structures have been placed in the Chippewa's wetlands.

Artificial impoundments facilitate manipulation of water levels, allowing for the maintenance of open water in places that had been choked with too much vegetation for optimum wildlife use. Water levels can also be lowered periodically to permit the oxidation of plant nutrients trapped in the sediments, to prevent drowning of desirable shrubs, and to stimulate the growth of emergent vegetation. The subsequent controlled reflooding retards hydric succession, maintains the emergent vegetation, and allows aquatic animals to utilize the new vegetative growth.

Our study assesses the response of vertebrates to the establishment of low-head dams constructed to flood less productive sedge meadows and shrub swamps. We did this by compiling lists of species using these artificial wetlands and comparing them with lists from known habitats and range, and those found in unmanaged wetlands.

Kirby (1975) listed the species of vertebrates he saw or found evidence of on beaver flowages in the Chippewa National Forest. His list, which included 37 mammals, 129 birds, 4 reptiles and 7 amphibians, provides a baseline for comparison with our results from water impoundments. In addition, there is some earlier information on avian use of the Chippewa impoundments (Mathisen *et al.* 1974).

While the primary objective of impounding wetlands is to increase waterfowl production, these habitats are attractive to other wildlife as well. They are important habitat for some sensitive or endangered species such as the bald eagles and ospreys, and they can support a variety of furbearing mammals and several important fish species, such as northern pike. Obviously, developed wetlands have high potential for recreational activities such as hunting, fishing, ricing and birding.

Edge habitats and patchy vegetation often support higher numbers of species and individuals than more homogeneous cover; this is particularly true of bird species. At least 30 of the land birds listed in the studies cited above almost certainly would not be present outside of marsh or edge habitat. Others would still be found in the surrounding woodland, but probably in lower densities.

This study assesses the value of impounded wetlands for wetland species, other wildlife that use the impoundments opportunistically, and for valuable or threatened species in particular. The benefits to wildlife of impoundments relative to unimproved wetlands are evaluated. The results presented permit preliminary predictions about the effects on wildlife of impoundment management and tentative recommendations concerning future impoundment sites.

METHODS

Studies were conducted on and adjacent to 11 impoundments containing various habitat types. Wildlife observations were made for 2 consecutive years (1978-1979) on nine of the impoundments, and for 1 year on the two remaining impoundments. Observations were made primarily from May through mid-October, with limited visits during the winter to record animal tracks and wintering birds. Observation periods lasted about 3 hours each, primarily in the early morning and late afternoon.

Observations were made at least once and usually twice a week at every impoundment. Platforms were constructed 10 to 14 m above ground in prominent trees along the edges of the impoundments, at points where the greatest portions of the impoundments were visible. Some observations were obtained while walking the perimeters.

Terrestrial birds within 100 feet of the impoundments were counted using sight, sound, and nest observations. They were then assigned to relative abundance categories and classified as being resident, breeding, migrant, or visitor. The same data were obtained for water birds. Mammals in and adjacent to the impoundments were recorded using sightings, tracks, scats, and other signs. Small mammals were trapped in selected edge or drawdown habitats in August of 1978, and in emergent drawdown habitat in August of 1979. Snap traps were positioned in pairs on a 8- x 17-m grid. Herptofauna were noted by sight and sound.

The following eight basic habitat types were recognized:

Water.—Almost all of the wetland vegetation and edges were interspersed with standing water for at least part of the year. We recognized large patches of open water not well mixed with other vegetation life forms as a separate type. In these shallow wetlands, most open water areas covered submerged aquatic vegetation.

Emergents.—Most emergent vegetation was flooded to 70 cm of water for much of the warm season. This type included broad-leafed emergents such as cattails (*Typha* spp.) and narrow-leafed emergents such as sedges, rushes, and grasses. Emergents were often interspersed with floating aquatic plants. This type often spatially overlapped other types such as dead timber, wetland shrubs, and seasonally flooded woodlands.

Wetland Shrubs.—Seasonally flooded shrubs, chiefly willow (*Salix* spp.) and speckled alder (*Alnus rugosa),* were distinguished from the under-story of the forests surrounding the impoundments. The wet substrate beneath these shrubs was often covered by herbaceous vegetation. The wetland shrubs that were permanently inundated were often in poor condition or dead.

Dead Timber.—The construction of low-head dams flooded portions of the surrounding forest. The resultant patches of dead trees created important habitat for cavity-nesting mammals and birds.

Deciduous Forest.—Broad-leafed forest was the most common edge type around the impoundments (55 percent of the Chippewa National Forest is typed aspen-birch, and 15 percent is northern hardwoods) (Kirby 1975). In addition to trembling aspen (*Populus tremuloides),* balsam poplar (*P. balsamifera),* paper birch (*Betula papyrifera)* and bur-oak (*Quercus macrocarpa),* the deciduous forests contained scattered red pine (*Pinus resinosa)* and white pine (*P. strobus).* The most common northern hardwood trees were sugar maple (*Acer saccharum),* green ash (*Fraxinus pennsylvanica),* yellow birch (*Betula alleghaniensis)* and red maple (*A. rubrum).*

Mixed Coniferous-broadleaf Forest.—Forest edges that were dominated by conifers or coniferous-broadleaf mixes formed the other forest edge type. The lowland conifer stands were composed of black spruce (*Picea mariana),* tamarack (*Larix laricina),* and northern white-cedar (*Thuja occidentalis).* The upland conifer stands were dominated by white pine and red pine, with scattered paper birch. Balsam fir (*Abies balsamifera)* was often mixed with green ash or aspen.

Ground/Mud.—Exposed mudflats, herbaceous fields, or snow cover surrounding the impoundments were in this category.

Aerial.—Because some species were only recorded in the air over the impoundments, we included this category.

RESULTS

The species recorded in four vertebrate classes were distributed as follows (Appendix I): 38 mammals, 147 birds, 4 reptiles, and 10 amphibians. The cumulative list—ours plus those of Mathisen *et al.* (1974)

and Kirby (1975)—is: 44 mammals, 167 birds, and 14 reptiles and amphibians. These species represent a considerable proportion of the vertebrate fauna found on the Forest as a whole. Of 308 vertebrate species listed on the Chippewa National Forest, (Mathisen 1980), 215 (70 percent) have been found in beaver flowages or water impoundments (77 percent of the mammals, 68 percent of the birds, 57 percent of the reptiles and 77 percent of the amphibians). The results are discussed below by vertebrate group (Appendix I) and habitat group (Appendix II).

Vertebrate Groups

Mammals

Mammalian species included 5 insectivores, 1 chiropteran, 12 carnivores, 16 rodents, 2 lagomorphs, and 2 ruminants. In addition, Kirby (1975) recorded the starnose mole, little brown myotis, least weasel, lynx, plains pocket gopher, and southern bog lemming on natural beaver flowages. Species we recorded in the impoundments that were not in the natural beaver flowages were the Arctic shrew, fisher, Franklin's ground squirrel, gray squirrel, eastern cottontail and moose. Most mammals were found at two or more impoundments and are probably well distributed. Some are nocturnal or secretive and may be more common than indicated in Appendix I. Others are more likely transients because suitable habitat is not commonly found in the impoundments (such as the Arctic shrews and ground squirrel) or because they are at the border of their ranges (such as the gray squirrel). It is unlikely that any of the mammals were found only in the artificial or only in the natural wetlands because of specific habitat preferences. Instead, the lists may be incomplete because of the chance element involved in recording rare or secretive animals. Individual impoundments had from 4 to 22 mammal species recorded, with an average of 12.1. In general, more species were found in the larger, more diverse impoundments.

Birds

One hundred forty-seven bird species were recorded in the impoundments, with a range of 60-106 and an average of 85 species per impoundment. As with the mammals, some species were found only in the artificial or only in the natural wetlands. This can be attributed to factors such as extent of observer coverage, season, or the presence of particular subhabitats. One exception is the greater diversity and number of migrant shorebirds found in the impoundments, due to the mudflats exposed during drawdown. Other wetland birds found only in impoundments included the short-billed marsh wren, northern waterthrush, Caspian tern, and common tern, but the latter two species were rare migrants. It seems likely that the short-billed marsh wren would be found in many natural wetlands. The other 13 birds not recorded in the beaver flowages were found at the edges of the impoundments; at least four of these were at the border of their geographic range (house wren, yellow-billed cuckoo, indigo bunting, hoary redpoll). The hoary redpoll and two shrike species were uncommon and mourning doves and bobolinks do not have appropriate habitat even at the edges of wetlands.

Of the birds that Kirby recorded in the beaver flowages but that were not found in our study or that of Mathisen *et al.*, the least bittern (which is difficult to glimpse or hear) is the only wetland species. The screech owl could probably be found at the edges of the impoundments. The white-winged crossbill is a visitor. Because typical habitat is lacking for the rufous-sided towhee, Savannah sparrow, vesper sparrow, and tree sparrow, sightings of these species would be a chance occurrence in any wetland.

Most bird species listed were recorded at the edges and also would be found away from wetland habitats. Some species are found only in wetland habitats. Other species are intermediate to the above, but their abundance is enhanced through opportunistic use of the impoundments.

The impoundments were attractive to a variety of water birds, including the common loons, pied-billed grebe, great blue heron, and American bittern. The most abundant ducks in the impoundments were the mallard, wood duck, ring-necked duck, and blue-winged teal. Birds of prey, such as the red-tailed hawk, American kestrel, osprey, and bald eagle, hunted in the impoundments and used snags and dead timber as perch sites. The sora and Virginia rails were seen and heard in emergent vegetation. The killdeer and spotted sandpiper were found at the water margins, and other migrant shorebirds used the mudflats exposed during drawdowns. Black terns nested in a few impoundments and belted kingfishers hunted over the open water.

Brown creepers, two species of nuthatches, and five species of breeding woodpecker were found principally in the dead timber. Flycatchers and swallows were attracted to the open nature of the impoundments, and three of the five swallow species were found at a majority of the impoundments. Both species of marsh wren were present in the emergents. Parids, thrushes, vireos, and tanagers were mostly confined to the upland edges. Common yellowthroats and yellow warblers were regular breeders in the wetland shrubs. Grackles used the water margins regularly, and redwinged blackbirds were abundant in the wetland vegetation. The swamp sparrow and song sparrow were the two most common finches associated with the impoundments.

Reptiles and Amphibians

Northern Minnesota has a depauperate herptofauna, and only 4 reptiles and 10 amphibians were found in the impoundments: two snakes, two turtles, two salamanders and eight anurans.

Individual impoundments supported 1 to 11 species, with an average of 4.9. The species found in a majority of the study areas were the western painted turtle, eastern garter snake, American toad, and northern leopard frog. The mink frog, wood frog, and eastern tiger salamander were near the border of their ranges and were not expected to be particularly abundant. Three species (blue-spotted salamander, wood frog, and green frog) not recorded by Kirby (1975) were found in less than half of the impoundments. The Chippewa National Forest is just north and west of many common, well-distributed species of amphibians and reptiles such as the wood turtle, map turtle, brown snake, northern water snake, bull snake, fox snake, eastern milk snake, bullfrog, and pickerel frog. As a result, the list of herptofauna is not as extensive as it would be in some other parts of the Lake States.

Impoundment Habitats

It is difficult to assess the influence of a given habitat type on an individual species or group of animals, since many species will use more than one habitat type, yet not be observed or trapped in all of them. Although some species may be present because of the proximity of a dissimilar habitat, others are found exclusively in one habitat type, or use some types more than others. Those species frequently showing up in more than one habitat type often did so because of the similarity of the types or interspersion of those types. For example, some mammals and birds were often found in both deciduous and mixed coniferous-deciduous forests, and feeding birds (aerial) often used dead timber for perch sites. Most waterfowl species used open water, dead timber, wetland shrubs, and emergents because of heavy interspersion of these types. Woodpeckers were found in both dead timber and the two forest categories. Appendix II lists the mammal and bird species found in each habitat type, and table 1 summarizes the numbers of species listed for each habitat type.

Open Water

The open water areas were used by eight mammalian species including muskrat, beaver, moose, mink and river otter. The principal avian users of open water were waterfowl, including 12 species of ducks. The common loon, osprey, American coot, and migrant terns used this habitat type exclusively.

Emergents

Eleven mammals were recorded in the emergent vegetation. In addition to those species found also in the open water, five small mammals were trapped in this type during a drawdown (three species of shrews, meadow vole, meadow jumping mouse). Emergents were used by 21 bird species, including most of the ducks in the open water, as well as the American bittern, black tern, and sora and Virginia rails. This habitat was also important to several passerine birds, including the swamp sparrow, eastern kingbird, redwinged blackbird, long-billed marsh wren and short-billed marsh wren. The latter two species, which depended on emergent vegetation as their chief habitat, were found in broad-leafed and narrow-leafed emergents, respectively.

Wetland Shrubs

The eight mammalian species observed in the shrub type were beaver, black bear, masked shrew, meadow vole, deer mouse, white-footed mouse, meadow jumping mouse, and the woodland jumping mouse (the latter was trapped only in this habitat). The common birds in the wetland shrub were the swamp sparrow, eastern kingbird, common yellowthroat and alder flycatcher. A number of the dabbling ducks and their broods used this type extensively. Most of the mammals and land birds in this habitat probably occur at similar densities in undeveloped wetlands.

Aerial

One group of animals did much or all of their foraging in the air, either capturing insects or sighting prey in or around the water from the air. The only bat sighted was the big brown bat. Aerial foragers most frequently sighted included the black tern, common nighthawk, chimney swift, cedar waxwing, osprey, bald eagle, five species of swallows, several species of hawks, and the four corvids. Snipe were observed performing aerial courtship displays over the impoundments. Thirteen of the 31 bird species were recorded only in the air. The insectivorous and piscivorous birds are probably more common near impoundments than in undeveloped wetlands because of more open water in the impoundments.

Dead Timber

The few mammals recorded in this type (table 1 and Appendix II) included seven small mammal species trapped during a drawdown: two shrews, two voles, two squirrels, and the meadow jumping mouse. Eight of the 44 bird species found in the dead timber areas were not recorded outside those areas, including the green heron, both shrikes, the red-headed woodpecker, and the tree swallow. The swallows were attracted by opportunities for nest cavities in the dead timber as were several other bird species. The shrikes, the belted kingfisher, and the flycatchers found perch sites on the snags. Birds reaching peak abundance in this habitat were the cedar waxwing, common grackle, and goldfinch. Bark foragers such as the woodpeckers, the nuthatches and the brown creeper may find abundant prey in the decaying wood.

Deciduous Forest

Deciduous forest and coniferous-broadleaf forest are abundant in the Chippewa National Forest, but are not wetland habitats. However, they form the major edge habitat in both artificial and natural wetlands, and many wetland species use the upland for important aspects of their life cycles such as nesting or cover. The two forest edges supported 19 mammalian species, but only seven of these were in the deciduous habitat. The gray squirrel was seen only in this habitat, while the fisher is rare throughout the Chippewa National Forest. Seventy-two bird species were observed in the forest edges, 37 of them exclusively. The 54 birds in the deciduous type represented the highest species count for any of the habitats (table 1). Nine avian species were found only in the deciduous forest, including the barred owl, yellow-billed cuckoo, house wren, wood thrush, three of the four vireos, and two of the 10 warblers. Most other families of land birds were also well represented in this habitat (Appendix II).

Mixed Forest

The mixed coniferous-broadleaf forest habitat type had 15 mammalian species, including seven small mammals. One of these, the northern flying squirrel, was trapped only in this type. Other species noted by sight or sign included the red squirrel, eastern chipmunk, porcupine, snowshoe hare, moose, white-tailed deer, and black bear. Forty-four bird species were recorded in the mixed forest, 15 of them exclusively. Exclusive species included the goshawk, gray jay, winter wren, Swainson's thrush, ruby-crowned kinglet, solitary vireo, and 6 of the 11 warblers.

Table 1.—*Bird and mammal species recorded by habitat type for 11 impoundments on the Chippewa National Forest (parentheses indicate the number of species found only in that type)*

	Species	
Habitat type	**Mammals**	**Birds**
	Number	
Water	8	18 (5)
Emergents	11	21 (4)
Wetland shrubs	8 (1)	32 (8)
Dead timber	12	44 (8)
Aerial	1	31 (13)
Deciduous forest	7 (1)	54 (9)
Mixed forest	15	44 (15)
Ground/mud	29 (11)	16 (11)

Ground/Mud

Twenty-nine mammals were recorded by sight, tracks, or trapping in impoundment edges such as fields, trails, snow-covered ice or seasonally dry sedge marsh. The following 11 species were found exclusively in these open areas, primarily detected by tracks in mud and snow: the Arctic shrew, both weasels, striped skunk, coyote, red fox, gray wolf, bobcat, two ground squirrels, and the eastern cottontail. There were signs or sightings of mink, river otter, moose, black bear, and fisher. Six birds of open areas were found in the grassy areas, and four of them (fox sparrow, dark-eyed junco, and both redpolls) were found exclusively in the open edges. The American woodcock was flushed from some field edges.

The mud margins and mudflats exposed by drawdowns were used by breeding killdeer, common snipe, and spotted sandpipers. The mudflats received substantial use by migrant shorebirds, such as solitary sandpipers, lesser and greater yellowlegs, least sandpipers, and pectoral sandpipers. While muddy margins around lakeshores and natural wetlands are common in the Chippewa National Forest, extensive mudflats are scarce, and this habitat may be the most unusual one created by artificial impoundments.

SUMMARY OF RESULTS

1. The species list of vertebrates recorded in the artificial water impoundments is remarkably similar to the list for natural beaver flowages. Most differences that do exist are almost certainly due to chance events rather than substantive habitat differences, especially for migrant birds and rare animals at their range borders. The major habitat difference that does exist between these two types of wetland is the presence of extensive mudflats that result from the scheduled drawdowns in the impoundments. These mudflats are particularly beneficial for shorebirds.
2. Impounded wetlands are valuable habitat for game species such as black bear, moose, white-tailed deer, waterfowl, rails, common snipe and American woodcock. In addition, these areas are used by furbearers such as red fox, muskrat, beaver, and some mustelids.
3. The wetlands can be important to endangered, threatened or sensitive species such as the fisher, timber wolf, common loon, bald eagle, and osprey.
4. a. The impoundments also maintain or enhance populations of wetland mammals such as the northern water shrew, river otter, and mink.
   b. Wetland bird species utilizing these impoundments include five waders, 15 waterfowl, three raptors (marsh hawk, bald eagle, osprey), two rails, eight shorebirds, three terns, the belted kingfisher, and two marsh wrens.
   c. Most of the reptiles and amphibians on the Chippewa are associated with wetland habitats, including the two turtles, two salamanders, and all eight anurans recorded in this study.
5. Still other vertebrate species should have higher populations because of the increased edge, interspersion, productivity, nest cavities, or perch sites present in these improved wetlands. Species enhanced are the eastern garter snake, masked shrew, short-tailed shrew, raccoon, at least two mustelids, and the meadow jumping mouse. Raptors using the impoundments opportunistically include the American kestrel, red-tailed hawk and broad-winged hawk. These wetland habitats also provide openings and abundant prey for insectivorous aerial foragers such as bats, the common nighthawk, the chimney swift and several swallow species. The dead timber provides nest cavities for the common goldeneye, hooded merganser, wood duck and American kestrel, as well as for several mammals and passerine birds. The flooded timber and snags are a foraging substrate for five woodpeckers, two nuthatches, and the brown creeper, and they provide perches for insectivorous hawkers (including four flycatchers, one woodpecker, and the cedar waxwing). Habitat is also maintained for several warblers and four species of sparrows that occupy hydric successional stages.

DISCUSSION

It is difficult to compare the results of this study with those conducted in other places in the Lake States, because of differences in habitat and geographic ranges of species. The study of Chippewa National Forest beaver flowages (Kirby 1975) is the most similar to the present study. Despite minor differences in methodology and observer coverage, the results are strikingly similar. We now need additional comparisons between impoundments and analogous undeveloped wetlands such as sedge meadows and shrub swamps.

One such study from southern Minnesota (Biebighauser 1979) reported the vertebrate inventories of two impoundment sites before flooding. Both sites had areas of wetland shrub and deciduous forest that were surveyed for vertebrate species composition. The list of reptiles and amphibians was similar to that of the Chippewa wetlands (within the limits of geographic ranges), but fewer mammal and bird species were recorded. This was not unexpected, however, because of the smaller area of wetland surveyed, the fragmentation of forest in southern Minnesota, and the distance from the boreal forest transition zone to the north. The impoundments were projected to be beneficial to wildlife because of stabilized water levels, more open water, additional edge, and greater interspersion and diversity of vegetation.

A vertebrate survey of the Sturgeon River Wilderness Area in the Upper Peninsula of Michigan (Crider 1979) included a larger proportion of upland habitat than our study. Nevertheless, the list of herptofauna totaled 13 species (11 in water and wetlands), similar to the 14 in our study. The proportion of reptiles relative to amphibians was higher in the Sturgeon River study, however. The mammal list from the Sturgeon River was somewhat smaller (29) than from the Chippewa (38), but three additional bat species were recorded. Only 100 bird species were listed, compared with our 147, a difference probably attributable to the more homogeneous upland habitat surveyed.

Another study in the Upper Peninsula McCormick Forest (Robinson and Werner 1975) listed 33 mammals out of an estimated possible 45 species, and 109 bird species out of 200-plus that could occur in that area. The McCormick Forest survey also covered a larger proportion of upland habitat than did our Chippewa Forest study. Eleven amphibians were found (four salamanders and seven anurans), compared with 10 in the Chippewa Forest wetlands. Five reptiles were listed in the McCormick Forest, including one snake not found in northern Minnesota. Robinson and Werner also estimated the biomass of amphibians in four habitats. They found that the upland forest supported an amphibian biomass an order of magnitude lower than those of three aquatic habitats. Among the aquatic study areas, bogs had twice the amphibian biomass of ponds, and over three times that of streams.

The Attraction of Wetlands to Wildlife

A number of factors cause wetlands to attract and support a high density and diversity of vertebrate species. One attraction is the water itself, which is directly responsible for the presence of 10 to 12 amphibians in most areas of the northern Lake States. Sources of drinking water can be important to many mammals. Open water holds a direct source of food for many vertebrates in the form of fish and aquatic insects. The openings above or adjacent to the open water allow additional species to harvest such resources. Kirby (1975) estimated that 4 mammals, 22 birds and 6 amphibians and reptiles would not have been present in the beaver flowages without the presence of open water. Most wetlands also produce an abundance of small seeds which are an important food source for birds and smaller mammals (Reese and Hair 1976). The high net primary productivity of wetlands supports the entire aquatic food chain. Flowages and impoundments with fluctuating water levels tend to retard hydric succession and maintain vegetation in younger stages of higher net productivity. Flooding also increases the perimeter and thus the amount of edge of the wetland and the interspersion among types. Where forest patches are killed by permanent or temporary flooding, dead trees provide animal dens and sites for cavity nesters.

Many bird species respond directly to the higher food availability discussed above. Other birds are attracted to the patterns of vegetation around the impoundments by more indirect mechanisms. For example, avian diversity is strongly related to the vertical complexity of foliage and number of vegetative life forms (MacArthur and MacArthur 1961, Willson 1974, Probst 1979). Horizontal complexity or patchiness adds habitat structure that can also increase avian diversity (MacArthur 1964, Roth 1976). Because water attracts bird species both directly and indirectly (Karr 1968), avian diversity increases on a gradient from simple upland forests to bottomland forests to beaver ponds (Reese and Hair 1976). Shorebirds can often benefit from water developments targeted for other objectives, such as flood control, reservoirs, municipal water supplies, and stock-watering ponds (Evans and Kerbs 1977). Because the mudflats that result from the impoundment drawdowns attract migrant shorebirds, drawdown schedules should accommodate the peak migration period in late August whenever possible.

Waterfowl benefits are a prime reason for wetland development, and impoundments can be as useful for waterfowl as natural wetlands (Brumsted and Hewitt 1952). The Chippewa impoundments support 32 to 68 pairs of nesting ducks each spring (Mathisen *et al.* 1974). Waterfowl production of managed wetlands in the forested areas of the Lake States compares favorably with some prairie marshes, especially during drought years (Hawkins and Green 1966). Without drawdowns, older impoundments become less attractive to ducks (Kadlec 1962, Nevers 1968).

Mammalian species also benefit from the productivity and habitat complexity of impounded wetlands. Small mammals are attracted to the margins, and some rodents, such as muskrat, utilize the emergents. The carnivores are drawn to the productive aquatic food chains, as well as to terrestrial animals that use wetlands for feeding or drinking. Several species, including the raccoon, mink, river otter, and beaver, center most of their activities on water.

Vertebrate Diversity and Relative Value of Habitat Types

To provide the best possible wildlife habitat in these impoundments, land managers should strive to select sites that will provide significant amounts of wetland shrubs, open water, emergent vegetation, and flooded dead timber. It is necessary to maintain some openings as field and shrubland adjacent to impoundments for maximum vertebrate diversity. Some sites should be managed for specific habitats or a restricted range of species, since it is not always possible to provide optimal habitat for all species. This is especially true for smaller impoundments. For example, small wetlands with a high proportion of flooded timber could be oriented toward wood ducks.

The two forest edges in our study supported 72 bird species, 37 of which were not found in any other habitats. While more bird species were recorded in the deciduous forest edge than in the mixed forest edge, the latter held more unique species and over twice as many mammal species (table 1). However, these forest edge types are abundant throughout the Chippewa National Forest and are not a major concern for impoundment management. The large areas of water created by the impoundments were of prime benefit to waterfowl, especially diving ducks. Open water is also of particular use to ospreys and belted kingfishers. Based on our experience at the East Lake Impoundment, two hectares of open water should be enough to attract waterfowl preferring that habitat.

The majority of the aerial foraging birds and bats could be found in most openings in both wetland and upland habitat. All bird and mammal species found in the open water were also recorded in the emergent vegetation, but additional species were found there; it is especially important to ducks, American bitterns, marsh wrens, and swamp sparrows. The wetland shrubs enhanced populations of several warblers and many duck species. The flooded timber habitat attracted few mammals, but 44 bird species used this type, including eight unique to that type. The emergents appeared to support the greatest number of wetland species, even though the other two wetland types may have held more unique species or more species that use the impoundments opportunistically.

In our study, most ducks showed some preference for single habitats within the impoundments (Appendix II and Caple 1972). For example, American wigeon and blue-winged teal were most often found in emergents, and open water was the preferred habitat of the common goldeneye, ring-necked duck, and hooded merganser. However, almost all species used a number of habitats for some or all of their breeding cycle.

Artificial structures can be beneficial to waterbirds for nesting, loafing and roosting. Nest boxes on the Chippewa were used by wood ducks, common goldeneyes, and hooded mergansers, and pushup islands and floating sedge mats were used for resting and limited nesting by ducks. The sedge mats were particularly valuable as common loon nest sites, and nest success is probably higher on the mats than at natural sites (Mathisen *et al.* 1974).

RECOMMENDATIONS FOR MANAGERS

1. To provide appropriate habitat for a variety of vertebrate species, managers should select impoundment sites that can produce substantial areas of open water, emergent vegetation, wetland shrubs, and dead timber.

2. To achieve maximum vertebrate diversity, open areas such as fields and shrublands should be maintained in adjacent uplands.

3. It may not be practical to attempt to provide optimum habitat for all species, especially at smaller impoundments. Some sites should be managed for specific habitats and a more restricted range of species.

4. If an impoundment is to be managed for specific target species, it may be important to consider the composition of the surrounding uplands in site selection and subsequent management.

5. Artificial structures such as nest boxes, sedge mats and push-up islands can benefit several vertebrate species.

6. Drawdowns should be scheduled to accommodate peak shorebird migration, if this does not compromise other management objectives.

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APPENDIX I: OCCURRENCE OF IMPOUNDMENT VERTEBRATES

MAMMALS 1978 & 1979

Species	Amik (1979) (108A)	Ball Club (49A)	Bear Brook (58A)	Beaver Lodge (77A)	Brush Lake (26A)	Cuba (1978) (29A)	East Lake (15A)	Hanson Lake (94A)	Ketchum (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Masked shrew *Sorex cinereus*			V[1]	V[1]		V[1]		V[1]	V[1]			
Arctic shrew *Sorex arcticus*										V[1]		
N. Water shrew *Sorex palustris*								V		V		V[1]
Pygmy shrew *Microsorex hoyi*									V[1]			V
Short-tailed shrew *Blarina brevicauda*			V[1]			V[1]		V[1]	V[1]	V[1]	V[1]	V[1]
Starnose mole *Condylura cristata*												V[1]
Little brown myotis *Myotis lucifugus*												V[1] +
Big brown bat *Eptesicus fuscus*					V			V				V
Black bear *Ursus americana*	S			V	V/S	V	S	S			S	V+
Raccoon *Procyon lotor*	S		V	S		V		S	V+		V	V+
Fisher *Martes pennanti*				S					V			
Short-tailed weasel *Mustela erminea*				S								V
Least weasel *Mustela rixosa*												V[1]
Long-tailed weasel *Mustela frenata*					V							V
Mink *Mustela vison*				S							V	V
River otter *Lutra canadensis*	V		V	V	V	S		V				V[1]
Striped skunk *Mephitis mephitis*		V		S				S		V		V+
Coyote *Canis latrans*								S		V		V
Wolf *Canis lupus*				S								C
Red fox *Vulpes fulva*			S									V+
Lynx *Lynx canadensis*												V
Bobcat *Lynx rufus*				S								S+
Woodchuck *Marmota monax*					V			V				V+
13-lined ground squirrel *Spermophilus tridecemlineatus*								V				V+
Franklin's ground squirrel *Spermophilus franklini*				V								

(table continued on next page)

(table continued)

Species	Amik (1979) (108A)	Ball Club (49A)	Bear Brook (58A)	Beaver Lodge (77A)	Brush Lake (26A)	Cuba (1978) (29A)	East Lake (15A)	Hanson Lake (94A)	Ketchum (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Eastern chipmunk *Tamias striatus*	V	V	V^1	V	V	V^1	V	V	V			V+
Red squirrel *Tamiasciurus hudsonicus*	V		V	V	V	V	V	V	V			V+
Gray squirrel *Sciurus carolinensis*		V										
N. flying squirrel *Glaucomys sabrinus*								V^1				V^1 +
Plains pocket gopher *Geomys bursarius*												S
Beaver *Castor canadensis*	S	S	V		V				V	V	V	V+
Deer mouse *Peromyscus maniculatus*			V^1	V^1		V^1		V^1				V^1
White-footed mouse *Peromyscus leucopus*			V^1	V^1		V^1		V^1		V^1		V+
Southern bog lemming *Synaptomys cooperi*												V^1
Boreal redback vole *Clethrionomys gapperi*						V^1		V^1				V^1 +
Meadow vole *Microtus pennsylvanicus*				V^1		V^1		V	V	V^1		V+
Muskrat *Ondatra zibethica*	V		V	V	V		V	V	V	V	V	V+
Meadow jumping mouse *Zapus hudsonicus*			V^1	V^1	V^1	V^1		V	V^1			V
Woodland jumping mouse *Napaeozapus insignis*				V^1								V
Porcupine *Erethizon dorsatum*	S				V						V	V+
Snowshoe hare *Lepus americanus*			V	V+				V			V+	
E. cottontail *Sylvilagus floridanus*		V	V						V			
Moose *Alces alces*				V+			S					
White-tailed deer *Odeocoileus virginianus*	S		V	V	V	V	V	V	V+	V	V	V+

Note: V — visual observation of the animal
V^1 — specimen captured or found dead
S — tracks or scats found
C — no visual observation, call noted
+ — young +/or nest observed

BIRDS 1978 & 1979

Species	Amik* (1979) (108A)	Ball* Club (49A)	Bear Brook (58A)	Beaver* Lodge (77A)	Brush Lake (26A)	Cuba* (1978) (29A)	East* Lake (15A)	Hanson* Lake (94A)	Ketchum* (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Loons	B*	B*		B*			B*	B[1]				
Common loon												
Grebes												
Horned grebe				*								
Pied-billed grebe	B*	B[1]*	B	B[1]*	B	B	B[1]*	B[1]*	*		B[1]	x
Herons and allies												
Great blue heron	B*	B*	B	B*	B[1]	B*	B*	B*	B*	B	B	x
Green heron	*		B	B*					*		B	x
American bittern	B*	*	B	B[1]*			B[1]	B[1]*	B[1]	B[1]	B	x
Least bittern												x
Great egret			M									
Waterfowl												
Canada goose			M			M	M	M				
Mallard	B[1]*	B[1]*	B[1]	B[1]*	B[1]	B[1]*	B*	B[1]*	B[1]*	B[1]	B[1]	x
Black duck							M					x
Pintail		M		M								
Gadwall		M	M	M								
American wigeon	*	B*	B[1]	B*	B				B	B	B	x
Shoveler				*								
Blue-winged teal	B[1]*	B[1]*	B[1]	B[1]*	B[1]	B*	B*	B[1]*	B[1]*	B[1]	B[1]	x
Green-winged teal	B*	B[1]*	B[1]	B[1]*		*	B*	B		B[1]		x
Wood duck	B[1]*	B[1]*	B[1]	B*	B[1]	B[1]*	B[1]*	B[1]*	B[1]*	B[1]	B[1]	x
Ring-necked duck	B[1]*	B[1]	B[1]	B[1]*	B		B[1]*	B*	B[1]	B[1]	B[1]	x
Lesser scaup		*										
Common goldeneye		B	B	B*	B[1]	B[1]*	B[1]*		B[1]*	B[1]	B[1]	x
Bufflehead	*	*		*	M		*					x
Hooded merganser		B*	B[1]	B[1]*	B	B*	B[1]*	B[1]*	B*		B	x
Vultures, hawks, falcons												
Turkey vulture	B*	B	B	B	B	B		B	B	B	B	x
Goshawk				R	R			R			R	x
Cooper's hawk				B					B			x
Sharp-shinned hawk			B		B			B	B	B	B	x
Marsh hawk		*		S				S	S	S		x
Rough-legged hawk												x
Red-tailed hawk	B	B*	B	B			B	B[1]*	B	B	B	x
Broad-winged hawk		B*	B	B	B	B	B*	B	B*	B	B	x
Red-shouldered hawk					B	B				B	B	
Bald eagle	B[1]*	B*	B	B	B		*	B	B*		B	x
Osprey	B*	B*	B	B*	B	B		B	B*	B	B	x
Kestrel	B	B*	B	B*	B[1]	B	B	B	B	B	B	x
Gallinaceous birds												
Ruffed grouse		R[1]*	R	R[1]*		R	R*	R	R	R	R	x
Cranes and allies												
Virginia rail		B[1]						B[1]				x
Sora rail	B	B[1]*	B[1]	B[1]		B		B[1]	B[1]*	B[1]	B[1]	x
American coot		M	M	*					M	M		x
Shorebirds												
Semipalmated plover			M									
Killdeer	B	B		B*	B			B[1]	B*	B	B	x
American woodcock			B	B*				B	B	B		x
Common snipe	B*	B*	B	B[1]				B[1]	B*	B	B	x

(table continued on next page)

(table continued)

Species	Amik* (1979) (108A)	Ball* Club (49A)	Bear Brook (58A)	Beaver* Lodge (77A)	Brush Lake (26A)	Cuba* (1978) (29A)	East* Lake (15A)	Hanson* Lake (94A)	Ketchum* (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Shorebirds, cont.												
Solitary sandpiper	M		M	M	M	*	M	M	M*	M	M	
Spotted sandpiper	B*			B*	B[1]		B[1]*	B[1]	B		B	x
Lesser yellowlegs	M*		M	M*			M		M	M	M	
Pectoral sandpiper				M*						M	M	
Least sandpiper				M								
Greater yellowlegs			M	M					M			
Terns												
Black tern	B*	B*	B	B[1]*	B			B[1]	B	B	B	x
Common tern	*	M										
Caspian tern	*											
Pigeons and doves												
Mourning dove		*							B			
Cuckoos												
Black-billed cuckoo			B	B	B			B	B		B	x
Yellow-billed cuckoo					B							
Owls												
Great horned owl				*		R		R	R			x
Barred owl	*		R	R	R			R			R	x
Screech owl												x
Goatsuckers												
Common nighthawk	B*				B		B	B	B*	B	B	x
Swifts												
Chimney swift					B	B*			B		B	x
Hummingbirds												
Ruby-throated hummingbird	B	B*	B	B*	B	B*	B[1]	B	B*		B	x
Kingfishers												
Belted kingfisher	B*	B[1]*	B[1]	B[1]*	B[1]	B*	B[1]	B[1]*	B[1]*	B	B	x
Woodpeckers												
Common flicker	B*	B*	B[1]	B*	B[1]	B[1]*	B*	B[1]*	B*	B	B	x
Pileated woodpecker		*	R	R	R	R*		R	R*		R	x
Yellow-bellied sapsucker	B*	B*	B	B	B	B*	B*	B*	B*		B	x
Hairy woodpecker	R*	R*	R	R	R	R	R	R	R*	R	R	x
Downy woodpecker	R	R	R	R	R	R	*	R	R			x
Black-backed three-toed woodpecker	*								*			x
Red-headed woodpecker		M	M		M	M			M		M	
Flycatchers												
Eastern kingbird	B[1]*	B[1]*	B[1]	B[1]*	B	B*	B*	B[1]*	B[1]	B[1]	B[1]	
Great-crested flycatcher	B*	B*	B	B*	B[1]	B*	B*	B	B*	B	B	x
Eastern phoebe	B[1]*	B	B	B[1]*	B	B			B		B	x
Alder flycatcher	B	B	B	B	B			B	B	B	B	x
Least flycatcher	*	B[1]*	B	B*	B	B*	B*	B*	B[1]*	B	B	x
Eastern wood pewee	B	B	B	B	B	B*	B	B	B		B	x
Olive-sided flycatcher	B*		B	B	B		B	B		B	B	x
Swallows												
Barn swallow	*		B	B*				B*	B*	B[1]	B	x
Cliff swallow								B	B			x
Rough-winged swallow		B							B		B	x
Tree swallow	B[1]*	B[1]*	B[1]	B[1]*	B[1]	B[1]*	B[1]*	B[1]*	B[1]*	B[1]	B[1]	x
Purple martin	B[1]*	*		B	B	B			B*		B	x

(table continued on next page)

(table continued)

Species	Amik* (1979) (108A)	Ball* Club (49A)	Bear Brook (58A)	Beaver* Lodge (77A)	Brush Lake (26A)	Cuba* (1978) (29A)	East* Lake (15A)	Hanson* Lake (94A)	Ketchum* (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Jays and crows												
Blue jay	R*	R*	R	R	R	R*	R*	R[1]*	R*	R	R	x
Gray jay	R*			R				R		R		x
Common crow	B*	B	B	B	B	B	B	B	B	B	B	x
Common raven			R	R	R	R	R	R	R	R		x
Chickadees												
Black-capped chickadee	R*	R*	R	R*	R	*	R*	R*	R*	R	R	x
Nuthatches and creepers												
White-breasted nuthatch	R	R	R		R	R*	R	R	R*	R	R	x
Red-breasted nuthatch	R*	R	R	R	R		R	R	R		R	x
Brown creeper					B	B		B				x
Wrens												
House wren				B	B			B			B	
Winter wren	B			B	B		B			B	B	x
Short-billed marsh wren			B					B[1]	B[1]	B[1]	B	
Long-billed marsh wren	B	B						*	B[1]*	B[1]	B	x
Mockingbirds and thrashers												
Catbird	B	B*	B[1]	B[1]*	B		*	B[1]*	B*	B[1]	B[1]	x
Brown thrasher				*								
Thrushes												
Robin	B*	B*	B	B*	B	B*	B*	B[1]*	B*	B	B	x
Wood thrush			B						B			x
Hermit thrush	B				B			M		B		x
Swainson's thrush								M				
Veery	B*	B*	B	B*		B*	B*	B[1]*	B*	B	B	x
Kinglets												
Golden-crowned kinglet												x
Ruby-crowned kinglet		M*			M			M	M		M	x
Waxwings												
Cedar waxwing	B*	B*	B	B*	B	B	B*	B*	B*	B	B	x
Shrikes												
Northern shrike				M								
Loggerhead shrike				S						S		
Starlings												
Starling	B*	B*		B			B	B[1]				
Vireos												
Solitary vireo	B		M					M	*			x
Red-eyed vireo	B*	B[1]*	B[1]	B[1]*	B[1]	B[1]*	B[1]*	B*	B[1]*	B[1]	B[1]	x
Philadelphia vireo									B			
Warbling vireo		B	B	B			B		B	B	B	
Yellow-throated vireo		B	B		B	B					B	x
Warblers												
Magnolia warbler	B			B		B					B	x
Blackpoll warbler	*							*				
Black and white warbler	B*	B	B	B	B		B*	B	B	B	B	x
Tennessee warbler						B	*					x
Nashville warbler	B	B	B	B	B			B	B	B	B	x
Parula warbler	B*	B	B	B*	B		B*	*	B*	B		x
Cape May warbler											M	x
Yellow-rumped warbler	B*	B	M	M	M		M	M	M	M	M	x

(table continued on next page)

(table continued)

Species	Amik* (1979) (108A)	Ball* Club (49A)	Bear Brook (58A)	Beaver* Lodge (77A)	Brush Lake (26A)	Cuba* (1978) (29A)	East* Lake (15A)	Hanson* Lake (94A)	Ketchum* (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Black-throated green warbler	B*		B	B*			B				B	x
Blackburnian warbler	B	B	B	B*			B				B	x
Chestnut-sided warbler	B	B*	B	B	B	B	B	B^{1*}	B*	B	B	x
Bay-breasted warbler												x
Pine warbler	B	B	B	B					B			x
Palm warbler	*			M		*	*	M				
Ovenbird	B*	B*	B^{1}	B*	B	*	B*	B*	B*	B	B	x
Northern waterthrush	B			B^{1}		B^{1}	B^{1}			B^{1}		
Yellowthroat	B*	B^{1*}	B^{1}	B^{1*}	B	B*	B*	B^{1*}	B^{1*}	B^{1}	B^{1}	x
Mourning warbler			B	B*	B	B	B*	B^{1}	B		B	
Connecticut warbler									B		B	x
Wilson's warbler	*	M	M								M	x
Canada warbler	B								M			x
American redstart	B*	B	B	B^{1}	B		B*	B	B	B	B	x
Golden-winged warbler			B	B				B^{1}	B	B	B	x
Yellow warbler	B*	B*	B^{1}	B	B	*	B*	B^{1}	B^{1}	B^{1}	B^{1}	x
Blackbirds and orioles												
Bobolink				M				M	M			
Yellow-headed blackbird	*											
Red-winged blackbird	B^{1*}	B^{1*}	B^{1}	B^{1*}	B^{1}	B^{1*}	B^{1*}	B^{1*}	B^{1*}	B^{1}	B^{1}	x
Brewer's blackbird												x
Common grackle	B*	B*	B^{1}	B*	B	B*	B*	B^{1*}	B^{1*}	B	B^{1}	x
Brown-headed cowbird	B	B	B	B^{1}	B	B*	B	B*	B	B		x
Northern oriole	B*	B*	B	B*	B	B^{1*}	B*	B^{1*}	B*	B	B	x
Tanagers												
Scarlet tanager	*	B	B	B	B	B	*	B	B	B	B	x
Grosbeaks, finches, sparrows and buntings												
Rose-breasted grosbeak	B*	B*	B	B*	B	B*	B*	B^{1*}	B*	B	B	x
Evening grosbeak				R				R*	R		R	x
Indigo bunting	B*	B*	B*									
Purple finch			B	B*	B	B		B	B		B	x
Pine grosbeak			W									x
Common redpoll						W	W					x
Hoary redpoll						W						
Pine siskin												x
American goldfinch	B	B	B	B	B^{1}	B^{1*}		B	B	B	B	x
White-winged crossbill												x
Red crossbill								W				
Rufous-sided towhee												x
Savannah sparrow												x
LeConte's sparrow			M	M								x
Vesper sparrow												x
Dark-eyed junco				M	M			M				x
Tree sparrow												x
Chipping sparrow	B*	B	B				B	B	B	B	B	x
Clay-colored sparrow												x
White-throated sparrow	B*	B		B*		*	B	B	B	B	B	x
Fox sparrow	*			M								x
Swamp sparrow	B	B^{1}	B^{1}	B^{1}	B	B^{1}		B^{1}	B^{1}	B^{1}	B^{1}	x
Song sparrow	B^{1*}	B^{1*}	B^{1}	B^{1*}	B^{1}	B^{1*}	B^{1*}	B^{1*}	B^{1*}	B^{1}	B^{1}	x
Snow bunting												x
	77	80	94	106	83	60	67	98	100	79	96	

Note: R— Resident year-round
B— Breeds–does not winter
M— Migrant
W— Winter visitor
S— Summer visitor (non-breeding)

*–Mathisen Study (1974)

R^1, b^1–Nest located within 33 m of impoundment or nesting inferred by other means.

REPTILES & AMPHIBIANS 1978 & 1979

Species	Amik (1979) (108A)	Ball Club (49A)	Bear Brook (58A)	Beaver Lodge (77A)	Brush Lake (26A)	Cuba (1978) (29A)	East Lake (94A)	Hanson Lake (94A)	Ketchum (51A)	Six Mile (24A)	Sucker Bay (41A)	Kirby Study (1973)
Snapping turtle *Chelydra serpentina*		V						V		V		V
W. painted turtle *Chrysemys picta belli*	V	V	V	V	V		V	V	V	V		V
N. red-bellied snake *Storeria occipitomaculata*				V				V				V
E. garter snake *Thamnophis sirtalis s.*		V	V	V	V		V	V	V		V	V
Blue-spotted salamander *Ambystoma laterale*				V								
E. tiger salamander *Ambystoma tigrinum t.*									V			V
American toad *Bufo americanus*	C			V	V			V	V	V		V
N. spring peeper *Hyla crucifer*	C						C		C		C	V
E. gray tree frog *Hyla versicolor*								V			V	V
Chorus frog *Pseudacris triseriata*								C	C			V
N. leopard frog *Rana pipiens p.*	V	V	V					V	V		V	V
Mink frog *Rana septentrionalis*	C			C				C				V
Green frog *Rana clamitans*				V				V		V		
Wood frog *Rana sylvatica*				V			V	V				
	5	3	4	8	3		4	11	7	4	4	

APPENDIX II: HABITATS OF IMPOUNDMENT VERTEBRATES
MAMMALS 1978 & 1979

Species	Water	Emergents	Deciduous forest	Mixed forest	Dead timber	Wetland shrubs	Openings			Kirby Study (1973)
							Aerial	Herbs (ground)	All impound.	
Masked shrew *Sorex cinereus*		V[1]		V[1]	V[1]	V[1]			x	
Arctic shrew *Sorex arcticus*								V[1]	x	
N. water shrew *Sorex palustris*	V							V[1]	x	V[1]
Pygmy shrew *Microsorex hoyi*		V[1]								V
Short-tailed shrew *Blarina brevicauda*		V[1]		V[1]	V[1]			V[1]	x	V[1]
Starnose mole *Condylura cristata*										V[1]
Little brown myotis *Myotis lucifugus*										V[1]
Big brown bat *Eptesicus fuscus*					V		V		x	V
Black bear *Ursus americanus*			V	V		V		V	x	V
Raccoon *Procyon lotor*	V	V	V					S	x	V
Fisher *Martes pennanti*			V					S	x	
Short-tailed weasel *Mustela erminea*								S		V
Least weasel *Mustela rixosa*										V[1]
Long-tailed weasel *Mustela frenata*								V		V
Mink *Mustela vison*	V							S	x	V
River otter *Latra canadensis*	V	V						S	x	V
Striped skunk *Mephitis mephitis*								S	x	V
Coyote *Canis lutra*								S	x	V
Gray wolf *Canis lupus*								S	x	C
Red fox *Vulpes fulva*								S	x	V
Lynx *Lynx canadensis*										V
Bobcat *Lynx rufus*								S	x	S
Woodchuck *Marmota monax*				V				V	x	V
13-lined ground squirrel *Spermophilus tridecemlineatus*								V	x	V
Franklin's ground squirrel *Spermophilus franklini*								V	x	
Eastern chipmunk *Tamias striatus*			V	V[1]	V[1]			V	x	V
Red squirrel *Tamiasciurus hudsonicus*				V	V			V	x	V
N. flying squirrel *Glaucomys sabrinus*				V[1]					x	V[1],S
Plains pocket gopher *Geomys bursarius*										S
Beaver *Castor canadensis*	V	V				V		S	x	V
Deer mouse *Peromyscus maniculatus*				V[1]	V[1]	V[1]		S	x	V[1]

(table continued on next page)

(table continued)

Species	Water	Emergents	Deciduous forest	Mixed forest	Dead timber	Wetland shrubs	Openings Aerial	Openings Herbs (ground)	Openings All impound.	Kirby Study (1973)
White-footed mouse *Peromyscus leucopus*				V^1	V^1	V^1		V^1	x	V
Southern bog lemming *Synaptomys cooperi*										V^1
Boreal red-backed vole *Clethrionomys gapperi*				V^1	V^1				x	V^1
Meadow vole *Microtus pennsylvanicus*		V			V^1	V^1		V^1	x	V^1
Muskrat *Ondatra zibethica*	V	V							x	V
Gray squirrel *Sciurus carolinensis*			V							
Meadow jumping mouse *Zapus hudsonius*		V^1		V^1	V^1		V^1	V^1	x	V^1
Woodland jumping mouse *Napaeozapus insignis*						V^1			x	V
Porcupine *Erethizon dorsatum*			V	V					x	V
Snowshoe hare *Lepus americanus*				V			V		x	V
Eastern cottontail *Sylvilagus floridanus*							V			x
Moose *Alces alces*	VV	VV		VV	VV		S			x
White-tailed deer *Odocoileus virginianus*	V	V	VV	V	V			V S	x	V

Note: Code (Kirby's notation)

V = visual observation of the animal

V^1 = a specimen was captured or found dead

S = no visual observation, but tracks or scat found

C = no visual observation, but call noted

in cases where there is a double symbol, the second symbol refers to observation of young and/or nest.

BIRDS

Species	Water				Emergents				Deciduous forest				Mixed forest				Dead timber				Wetland shrubs				Aerial				Ground			
	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W
Loons																																
Common loon	3	2	3		4	4																										
Grebes																																
Pied-billed grebe	3	2	3		3	2	3																									
Herons and allies																																
Great blue heron	2	1	2		4	4	4										4	4	4													
Green heron																		4														
American bittern						2																										
Great egret					4																											
Waterfowl																																
Canada goose																											3					
Mallard	1	1	1		1	1	1										1	1	1		3	3	3									
Black duck		4																														
Pintail			4																													
Gadwall			3																				3									
American wigeon	2	3	2		2	3	2												4		4	4	4									
Blue-winged teal	1	1	1		1	1	1										3	3	3		3	3	3									
Green-winged teal	3	3	3		3	3	3														3	3	2									
Wood duck	1	1	1		2	2	2										1	1	1		1	1	1									
Ring-necked duck	2	1	2		3	2	3														3	3	3									
Common goldeneye	2	2	2		3	3	3										3	2	2													
Bufflehead	4																															
Hooded merganser	2	1	2		3	3	3										2	2	2		3	3	3									
Vultures, hawks, falcons																																
Turkey vulture																										2	2					
Goshawk													4	4	4	4																
Cooper's hawk														4												4						
Sharp-shinned hawk										3	3															3	3					
Marsh hawk																										4	3					
Red-tailed hawk										3	3			2	2			4							2	2	2					
Broad-winged hawk										3	3				4									2	3							
Red-shouldered hawk										3								4								3						
Bald eagle																		4	4							3	3					
Osprey	4	4	4																							2	2					
Kestrel																		2	2							2	2					
Gallinaceous birds																																
Ruffed grouse									2	2	2		2	2	2																	
Cranes and allies																																
Virginia rail						4																										
Sora rail					1	1	4																									
American coot			2																													
Shorebirds																																
Semipalmated plover																															4	
Killdeer																										2	2		2	2	2	
American woodcock										3	3			3	3															3	3	
Common snipe																		3	4						2	2	2					

(table continued on next page)

(table continued)

Species	**Water**				**Emergents**				**Deciduous forest**				**Mixed forest**				**Dead timber**				**Wetland shrubs**				**Aerial**				**Ground**			
	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W
Shorebirds cont.																																
Solitary sandpiper																													2		2	
Spotted sandpiper																													2	2	2	
Lesser yellowlegs																															3	
Greater yellowlegs																															3	
Pectoral sandpiper																															4	
Least sandpiper																															4	
Terns																																
Black tern					3	3																			2	2						
Common tern	4																								4							
Pigeons and doves																																
Mourning dove																										4						
Cuckoos																																
Black-billed cuckoo									3	3										3	3											
Yellow-billed cuckoo										4																						
Owls																																
Great horned owl									4	4	4		4	4	4																	
Barred owl									2	2	3	3																				
Goatsuckers																																
Common nighthawk																										3						
Swifts																																
Chimney swift																										3						
Hummingbirds																																
Ruby-throated hummingbird									3	3															3	2						
Kingfishers																																
Belted kingfisher																	2	2	3													
Woodpeckers																																
Common flicker										2	2						3	2	2											3	2	
Pileated woodpecker									3	3	3	3						3	3													
Yellow-bellied sapsucker										2	3							2	3													
Hairy woodpecker									2	2	2	2						3	3													
Downy woodpecker									2	2	2							2	2													
Red-headed woodpecker																	4		4						4		4					
Flycatchers																																
Eastern kingbird										3								1				2				3						
Great-crested flycatcher										2								2														
Eastern phoebe														3				3														
Alder flycatcher																				3												
Least flycatcher										1				2				3														
Eastern wood pewee										2								3														
Olive-sided flycatcher																		3														
Swallows																																
Barn swallow																										2						
Cliff swallow																										3						
Rough-winged swallow																									4	4						
Tree swallow																		1								1						
Purple martin																										3						

(table continued on next page)

(table continued)

Species	**Water**				**Emergents**				**Deciduous forest**				**Mixed forest**				**Dead timber**				**Wetland shrubs**				**Aerial**				**Ground**			
	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W
Jays and crows																																
Blue jay									2	2	2	2	2	2	2	2	3	3	3	3												
Gray jay													2	4	2	3																
Common crow										2	2		3	3	3											2	2					
Common raven																									2	4	2	2				
Chickadees																																
Black-capped chickadee									1	2	1	1	1	2	1	1																
Nuthatches and creepers																																
White-breasted nuthatch									3	3	3	3						3	3													
Red-breasted nuthatch									3	3	3	3	2	2	2	3																
Brown creeper															3	3	3	3	3													
Wrens																																
Winter wren													3	3																		
Short-billed marsh wren					2	2															3											
Long-billed marsh wren					2	2															4											
House wren										4																						
Mockingbirds and thrashers																																
Catbird										3											2											
Thrushes																																
Robin									2	2	2			4	4			3	3		4	4								3	3	
Wood thrush									4	4																						
Hermit thrush														4	4																	
Swainson's thrush													4		4																	
Veery										2				3																		
Kinglets																																
Ruby-crowned kinglet													3		3																	
Waxwings																																
Cedar waxwing									3	2								2			3					2						
Shrikes																																
Northern shrike																				4												
Loggerhead shrike																		4														
Starling																		3														
Vireos																																
Solitary vireo													4	4	4																	
Red-eyed vireo									2	1	4			3	4																	
Philadelphia vireo										4																						
Warbling vireo										3																						
Yellow-throated vireo										3																						

(table continued on next page)

(table continued)

Species	Water				Emergents				Deciduous forest				Mixed forest				Dead timber				Wetland shrubs				Aerial				Ground			
	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W
Warblers																																
Magnolia warbler													4	4																		
Black and white warbler									2	2	4		3	3	4																	
Nashville warbler																					3	3										
Parula warbler										3	4			3	4																	
Cape May warbler									4		4																					
Yellow-rumped warbler									2	3	2		1	3	1					2	4	2										
Black-throated green warbler													3	3	3																	
Blackburnian warbler													3	3																		
Chestnut-sided warbler									2	2	3			3	4					2	2	3										
Pine warbler													4	4	4																	
Palm warbler															2																	
Ovenbird									2	2	2		2	2	2																	
Northern waterthrush										2																						
Yellowthroat																				2	1	2										
Mourning warbler																					3											
Connecticut warbler														4																		
Wilson's warbler																				4												
Canada warbler																				4	4	4										
American redstart									2	2	3									2	2	3										
Golden-winged warbler										4											3											
Yellow warbler										3	3										1	3										
Blackbirds and orioles																																
Bobolink																									4	4						
Yellow-headed blackbird																										4						
Red-winged blackbird					1	1	2										1	1	2		1	1	2									
Common grackle									2	2	2		2	2	2		2	2	2		2	2	2									
Brown-headed cowbird									2	2	3		3	3	3		2	2	3													
Northern oriole									4	2	4			4				2				3										
Tanagers																																
Scarlet tanager										2	4			4																		
Grosbeaks, finches, sparrows and buntings																																
Rose-breasted grosbeak										1				3																		
Evening grosbeak										3				3	2																	
Indigo bunting										3								4	4													
Purple finch										3				3				3														
Pine grosbeak																4																
Common redpoll																																4
Hoary redpoll																																4
American goldfinch										4								2												3		
Red crossbill																4																
LeConte's sparrow																					4											
Dark-eyed junco																													1		1	
Chipping sparrow									4	4			4	4																		
White-throated sparrow																				2	3											
Fox sparrow																															4	
Swamp sparrow						3														2												
Song sparrow																		3														

Note: Sp–Mar 16-Jun 5
Sm–Jun 6-Aug 30
F–Sep 1-Nov 30
W–Dec 1-Mar 15

ABUNDANCE: 1–Abundant >5/day
2–Common 1-5/day
3–Regular 5 sightings/year
4–Occasional >1-5 sightings/year

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Probst, John R.; Rakstad, Donald; Brosdahl, Kathy.
Diversity of vertebrates in wildlife water-impoundments on the Chippewa National Forest. Res. Pap. NC-235. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 22 p.

Gives an annotated list of mammals, birds, reptiles and amphibians in 1978 and 1979 in forested wetlands of northern Minnesota. Describes habitat preferences of vertebrates, relative abundance of bird species, and general management recommendations for wildlife.

KEY WORDS: Mammals, birds, reptiles, amphibians, habitat preferences, relative abundance, species distributions, wetland management.

United States Department of Agriculture

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Research Paper **NC-236**

Modeling Aspen and Red Pine Shoot Growth to Daily Weather Variations

Donald A. Perala

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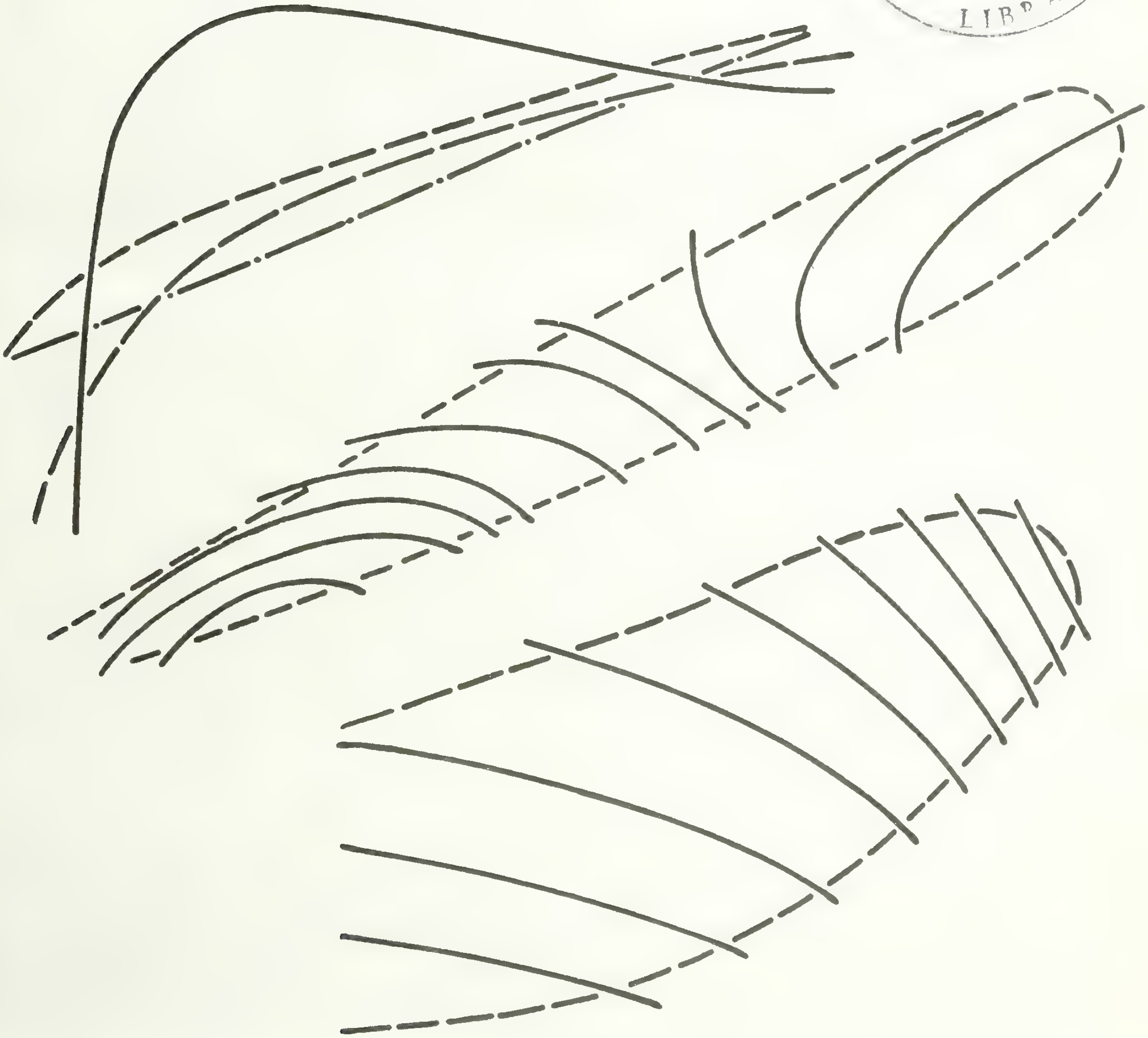

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MODELING ASPEN AND RED PINE SHOOT GROWTH TO DAILY WEATHER VARIATIONS

Donald A. Perala, *Principal Silviculturist, Grand Rapids, Minnesota*

Many investigators have attempted to correlate parallel measurements of shoot growth and meteorological variables (Ashton 1975, Cremer 1976, Dahl and Mork 1959, Hiley and Cunliffe 1923, Lanner 1964, Worrall 1973, among others). Hari *et al.* (1977) were especially successful and developed a dynamic model with good predictive value when applied to shoot growth of a number of plants.

Shoot growth models have a number of potential uses in forestry. By screening out microclimatic variation, they could be used to (1) bring into focus the annual rhythm of shoot growth—one of the best indicators of genetic climatic adaptation (Dietrichson 1971); (2) compare provenance and tree breeding trials over widely separated plantings and over different years (Hari and Leikola 1974, Parviainen 1974); and (3) define climatic provinces suitable for growing exotic or genetically improved trees. Also, reference models might aid in classifying sites and in evaluating silvicultural practices prescribed to modify forest microclimates such as competition control, nurse crops, topographic site selection, and regeneration systems. Herbicide testing and prescription could be improved by predicting plant metabolic activity, and hence sensitivity to herbicides (Aberg 1964), from local meteorological observations.

Development of shoot growth models has been hindered by (a) inadequate measurement frequency and accuracy, (b) complex interactions between environmental variables and plant requirement needs with maturity, (c) lag and displacement of plant response to environmental stimulus, (d) complex energy exchange between plants and environment, and (e) high correlation between meteorological variables (Ford 1980, Idso *et al.* 1966, Kramer and Kozlowski 1979). In the strictest sense, growth can never be unequivocally related to meteorological variation because natural environments are out of the control of the experimenter. On the other hand, the principles of plant growth are well established (Kramer and Kozlowski 1979) so that carefully interpreted empirical studies may provide theoretically sound working models for testing, refinement, and use.

This paper presents some equations that estimate shoot growth of juvenile quaking aspen (*Populus tremuloides* Michx.) and red pine (*Pinus resinosa* Ait.) from daily meteorological records. The underlying objectives of the study were to determine (1) if shoot growth measurement techniques and local standard climatological data could provide analytically usable data sets; (2) the usefulness of data gathered over daily and longer intervals; and (3) whether standard multiple linear regression of the data sets and transformations would provide coherent and theoretically sound shoot growth equations. The equations are by no means definitive because the data sets were limited and because of other weaknesses. On the other hand, they demonstrate that meteorological data may be much more useful than is generally conceded.

"Shoot growth" as used here means the difference between successive measures of shoot length and may include reversible changes due to hydration as well as irreversible changes due to tree growth (Cremer 1976, Milne *et al.* 1977).

METHODS

Shoot growth data were gathered near Grand Rapids, Minnesota, for two growing seasons (1978-1979) from planted red pine and for three seasons (1977-1979) from naturally regenerated aspen suckers (table 1). All trees were on level terrain and open-grown

Table 1.—*Characteristics of aspen and red pine measured for shoot growth*

Measurement year	Age[1]	Stocking	Total height[1]	Seasonal shoot growth	Duration of growth
ASPEN					
	Years	*1,000 stem/ha*	*m*	*mm*	Days[2]
1977	1	93	1.12–2.08	1,124–2,083	81
1978	2	72	1.94–2.50	667– 991	71
1979	3	48	2.52–2.96	437– 583	54
RED PINE					
1978	13	1.1	1.93–2.82	487– 777	59
1979	14	1.1	2.50–3.56	566– 795	61

[1] At end of measurement year. Red pine age is total age from seed (planted as 3-0 stock).

[2] First and last 5 percent of growth excluded.

with little or no mutual shading. The pines were separated from the aspen by 200 meters. The climate is continental—July temperatures average 20°C, annual temperatures average 4°C, and total annual precipitation averages 630 mm with about half falling during the growing season (May–August) (Aakre 1966). The soil is an unnamed silt loam having 5 percent gravel by weight and good internal drainage (table 2).

Terminal shoot growth of 10 quaking aspens and 10 red pines were measured mostly daily, however, in 1978 and 1979 up to 3 or 4 days and in 1977 up to 8 days occasionally lapsed between measurements. Measurements to the nearest mm with a steel tape were begun usually at 1400 hours, local standard time, but occasionally as late as 1530 hours. Maximum reading error was 1 mm based on spot checks. Measurements were indexed to a permanent mark of India ink (red pine) or current year bud scale scar (aspen) and made to the meristematic tip or new terminal bud. The apical meristem of aspen was usually hidden by unfolding leaves during early growth. Meristem position was estimated with little loss of precision after gaining some experience by dissecting adjacent unmeasured shoot tips.

Table 2.—*General description of the soil on the study site*

Horizon	Depth	Texture	Roots
	cm		
A2	0–16	Silt loam	Abundant
B2	16–26	Sandy clay loam	Common
B3	26–36	Sandy clay loam	Common
C	36 +	Sand	Few

Several shoots were broken, injured by disease or insects, or had unusually slow or short periods of growth. These data were discarded, leaving as few as three aspens with usable data for 1979 (table 1). Accumulated shoot growth (Si) was averaged to the nearest 0.1 mm and for aspen in 1978 and red pine in 1979, by groups having similar growth duration. Periodic shoot growth (ΔS) is simply the difference between mean Si on successive measurements.

Maximum and minimum daily temperatures and daily precipitation were obtained from an offical weather station located about 1.3 km from the study site (U.S. Department of Commerce 1977-1979); daily wind speeds were obtained for Hoyt Lakes located 105 km northeast of Grand Rapids (U.S. Department of Commerce 1977-1979); and daily solar radiation and relative humidity for Grand Rapids were provided by the University of Minnesota.[1]

The following variables were derived from these data:

Tmax— Daily maximum air temperature, to nearest 0.1 C°.

Tmin — Daily minimum air temperature, as above.

Tgm — Geometric mean daily air temperature, $\sqrt{(\text{Tmax})(\text{Tmin})}$, as above.

---

[1] *Special appreciation goes to Drs. D. G. Baker and D. K. Wildung for making these data available.*

M — Daily soil moisture balance in a 66 cm rooting profile (depth of A2 + B2 + B3 + 30 cm of C soil horizons) estimated according to Thornthwaite and Mather (1955). Calculated maximum moisture retention summed for the profile is 100 mm. Water held at greater than 15 atmospheres is assumed to be unavailable to plant growth, 18 mm in this case (Brady 1974). Expressed in mm minus 18, to nearest mm.

Wo — Current day incoming solar radiation, to nearest cal/cm^2/day (Langleys/day).

W-1 — Previous day incoming solar radiation, as above.

E — Free surface evaporation, to nearest mm/day. Calculated according to a modified Penman equation (Gray *et al.* 1970),

$$E = \frac{\Delta H + \gamma Ea,}{\Delta + \gamma} \qquad \text{(Eq. 1)}$$

Where Δ = slope of the saturation vapor pressure-temperature curve at mean air temperature;
γ = a constant (0.49 mm Hg per °C) to keep units consistent;
and $H = \frac{Wo}{59}$ a conversion of solar radiation into mm of evaporated water.

Ea — (Evaporation power of the air, mm/day) is calculated:
$Ea = 0.35\,(e_s - e_a)(1 + 0.54\,\mu_2)$, (Eq. 2)
where $(e_s - e_a)$ is the saturation vapor pressure deficit. e_s was determined from List (1966, table 94); e_a from Brown (1973, fig. 9), based on daily mean air temperature and relative humidity (RH); and μ_2 = wind speed in m/sec. Mean RH was determined by excising the area between measurements under the hygrograph chart trace, weighing, and dividing by the weight of the 100 percent chart.

Each meteorological variable (Xi) associated with daylight hours—Tmax, Wo, and μ_2—was apportioned to the current and succeeding measurement period according to the portion of the solar day (Brown 1973) elapsed at measurement time. The synthesized variable (Xí) representing the measurement period was calculated:

$$Xí = \frac{P_o\,(Xi_o) + (1 - P_{-1})\,Xi_{-1})}{P_o + (1 - P_{-1})} \qquad \text{(Eq. 3)}$$

where "P" is portion of solar day and "o" and "-1" are subscripts for current and preceding day, respectively. W-1, Tmin, and M needed no adjustment. For measurement intervals of 2 or more days, mean daily Xi (or Xí) and their transformations were determined by averaging.

Sc/Sf (to the nearest 0.1 percent) and its ln transformation were introduced to test for inherent growth rhythms independent of the environment. "Sc" is cumulative shoot growth (mean of Si at beginning and end of the measurement period) and "Sf" is the final shoot measurement after terminal bud growth ceased.

Dummy variables (0,1) were used to identify different groups or measurement years within regressions.

To accommodate the variation in length of measurement period, the term ln DAYS was introduced. DAYS is simply the total minutes in the measurement period divided by 1440 min/day, to the nearest 0.01 day.

ΔS for each species-group was fitted over the independent climatic and derived variables using backward stepwise multiple linear regression. The general model was:

$$\ln \Delta S = b_o + b_1 \ln X_1 + b_2 X_1 + \ldots$$
$$b_i \ln X_i + b_j X_i. \qquad \text{(Eq. 4)}$$

This model was chosen because it is interactive, is adaptable to a wide variety of nonlinear relations (Freese 1964), and enforced minimal preconceived constraints on the relations between shoot growth and the environment. With each run, the least significant variable was omitted, with the restrictions that dummy variables were retained throughout and Sc/Sf variables were not omitted until the last run. This process was iterated until an equation with the smallest standard error was obtained. If plots of residuals over Xi (or Xí) revealed a trend, a new transformation was added to the maximum model and the entire stepwise procedure repeated until only random residuals remained.

During the analysis it became apparent that the beginning and ending 5 percent of growth were insensitive to environment—a common experience

(Lanner 1964, Worrall 1973). These observations were discarded, although they probably could be fit with nonlinear or other models (Hari and Leikola 1974).

RESULTS AND DISCUSSION

Environment and inherent growth rhythm accounted for 91 to 98 percent of the diurnal variation in shoot growth with 13 percent or less arithmetic standard error (table 3). With only two exceptions, terms in the final equations were significant at least at $P < 0.05$. Shoot growth was similar among species and ages in response to all environmental variables except soil moisture (figs. 1-3). None of these responses were necessarily inconsistent with currently understood principles of plant growth.

Sc/Sf (Cumulative Shoot Growth/Final Shoot Measurement)

Red pine had a stronger inherent growth rhythm than aspen (fig. 1). The rhythm for red pine has been noted before (Baldwin 1931, Cook 1941, Farnsworth 1955, Kienholz 1941, Kozlowski and Ward 1961, Kramer 1943) and is similar to that of Scotch pine, *Pinus sylvestris* L. (Vuokko *et al.* 1977).

Kienholz (1941) found a moderate growth rhythm for quaking aspen saplings but its real magnitude is questionable without accounting for the influence of microclimate. Hari and Leikola (1974) observed that European white birch, *Betula verrucosa* Ehrh., after a period of growth acceleration and after accounting for air temperature had a long period of stable growth. Quaking aspen appears to have a similar rhythm.

W-1 (Previous Day Incoming Solar Radiation)

The most consistent shoot growth response was to previous-day solar radiation (fig. 1). Response was strongly positive with no indication of approaching an upper asymptote. Shoot growth response to W-1 is partly due to photosynthate production, which is needed for metabolism and cell structure (Kramer and Kozlowski 1979), and partly due to soil warming, which is needed for root growth (Barney 1951) and absorption and uptake of nutrients and water (Kramer and Kozlowski 1979). Most of the fine feeder roots of aspen and red pine are found in the upper few centimeters of soil (Alban *et al.* 1978) where diurnal temperature may fluctuate up to 15°C or more (Cochran 1969).

M (Daily Soil Moisture)

Shoot growth response was least consistent with Thornthwaite estimates of available soil moisture (fig. 1). The theoretical response curve should consist of three zones: (1) a zone of rapidly increasing growth over increasingly available M from the wilting coefficient at 18 mm to about 40 mm; (2) an optimum zone from 40 mm to perhaps 80 mm available M; and (3) a zone of reduced growth from 80 to 100 mm because of impeded aeration by excess gravitational M (Brady 1974, Kramer and Kozlowski 1979). It appears that the red pine response is entirely in zone 1, third-year aspen in zones 1 and 2, second-year aspen in zone 2, and first-year aspen entirely in zone 3.

The reason for response displacement is related to errors in estimating M due to the unavailability of water use coefficients for adjusting differences in evapotranspiration between species and ages and to errors in estimating soil volume exploited by tree roots. Evapotranspiration is much less in regenerating aspen stands than in mature stands (Johnston 1970, Verry 1972) and at least 10 years are required before full canopy development and hence maximum evapotranspiration is regained (Ohmann *et al.* 1978). This would cause overestimates of soil moisture depletion in young stands. At age 13, red pine already has attained maximum rooting depth (Fayle 1975) so soil moisture depletion may have been underestimated. Soil warming rate is inversely related to soil moisture content (Cochran 1969) which would also slow shoot growth as discussed earlier.

Tmax and Tmin (Daily Maximum and Minimum Temperatures)

Some of the independent variables were highly correlated so it would be inappropriate to depict shoot growth response over one without considering another (table 4). Such is the case with maximum (day) and minimum (night) temperature. Additionally, Tgm was a significant variable for second- and third-year aspen.

Red pine shoot growth increased asymptotically with day temperature, and in third-year aspen, high day temperatures even became limiting in combination with high night temperatures, probably due to excessive respiration (Kramer and Kozlowski 1979)

Table 3.—*Equation coefficients (with statistics) to predict terminal shoot growth of aspen and red pine*

(In mm/day (ln units))

Independent variable	Variable form	Quaking aspen			Red pine, years 13 and 14
		Year 1	Year 2	Year 3	
		Coefficients (with t-value)			
Tmax	X				-.1783(-2.5)
	lnX	2.025(7.3)	5.206(3.5)	15.332(6.7)	5.916(3.5)
	X^2			-.004947(-5.8)	
Tmin	lnX		4.622(3.8)	7.141(3.9)	.4932(5.1)
	$_{e}$·18X	.01263(2.2)			
Tgm	lnX		-8.761(-3.4)	-14.12(-4.0)	
M	lnX	-.4384(-3.9)		2.098(2.8)	.3273(2.7)
	X			-.02808(-1.9)	
Wo	lnX		1.580(3.6)	3.117(7.4)	1.085(3.4)
	X	.002296(1.6)	-.004671(-3.7)	-.01056(-4.7)	-.003120(-2.1)
W-1	lnX	.8469(3.5)			.4053(6.7)
	X		.001835(5.8)	.001812(7.8)	
E	lnX	-1.571(-3.2)		-11.044(-4.6)	-5.576(-3.4)
	X			1.577(4.8)	.7742(3.4)
	X^{-1}		1.997(2.2)	-12.629(-3.6)	-6.268(-2.6)
Sc/Sf	lnX	.2296(2.4)	.6523(6.3)		1.792(12.4)
	X	.007385(-3.0)	-.01466(-4.4)		-.04645(-14.7)
Constant[1]	—	-6.08[2](6.4)	-11.162(4.2)	-30.965(8.7)	-20.042(4.8)
Standard error:					
ln		.0590	.1288	.0878	.1283
Percent[3]		5.9	13.0	8.8	13.0
Overall F		103	148	138	122
n[4]		20	41	27	60
R^2: Total equation[5]		.99	.98	.99	.98
Net equation[6]		.95	.91	.98	.95

[1] Corrected for logarithmic bias according to Baskerville (1972).
[2] Also adjusted for mean ln days (see text).
[3] Of arithmetic mean Y.
[4] Number of observations.
[5] Including ln DAYS and dummies (see table 5).
[6] Variation remaining after reduction by ln DAYS and dummies.

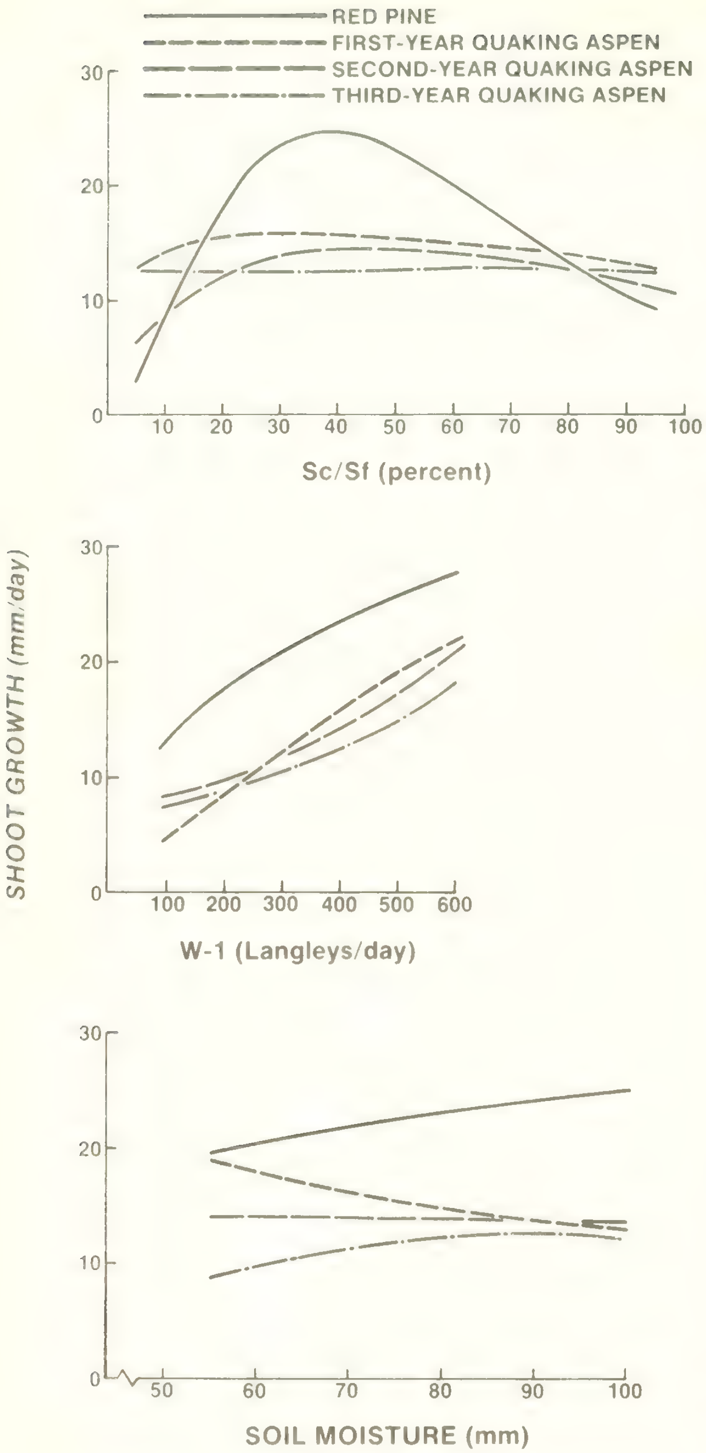

Figure 1.—*Diurnal shoot growth of red pine and first-, second-, and third-year quaking aspen in response to seasonal growth rhythm (Sc/Sf), previous-day incoming solar radiation (W-1) and Thornthwaite soil moisture. In these and subsequent figures, the fixed variables are held constant at their means (Wo and W-1 = 387, M = 80, Tmax = 25.8, Tmin = 11.3, E = 5.0, and Sc/Sf = 50).*

(fig. 2). In contrast, first-year aspen shoot growth increased exponentially with both increasing day and night temperatures; second-year aspen response was intermediate. Again, this strongly suggests the dependence young aspen suckers have on parent root carbohydrate reserves and the need for warm soil to make them available for growth. As suckers mature, these reserves are depleted and aspen must depend more on current photosynthate.

The range of shoot growth was consistently widest over E and Wo, followed in order by air temperature, W-1, and M. Other research has shown that air temperature is the major factor governing shoot growth (Ashton 1975, Dahl and Mork 1959, Lanner 1964, Mitscherlich *et al.* 1973, Worrall 1973). Indeed Hari and Leikola (1974) needed only growth rhythm and air temperature to predict from 91 to 96 percent of the variation in shoot growth of Scots pine in Finland. Adding other environmental variables to their model improved predictive ability less than 1 percent. They reasoned that soil moisture and solar radiation were not as limiting in boreal climates as they might be elsewhere.

E and Wo (Free Surface Evaporation and Current Day Solar Radiation)

The correlation between these variables is high because current-day solar radiation is the dominant variable in calculating free surface evaporation (Eq. 1) (table 4).

Red pine and third-year aspen shoot growth were similar—growth increased greatly with decreasing E and Wo (fig. 3). The reflexed isopleths in the region of high E and Wo indicates that growth increases slightly with increasing E. This is inconsistent with growth theory. The theoretical response should be a "flat" region of minimum growth. Likely this is a fault of the model induced by the size and precision of the data set. The fault is not serious if the low magnitude of growth is kept in perspective with the greatly increased shoot growth for the rest of the range.

The first-year aspen were unique in that shoot growth increased over the entire range of increasing Wo (given constant E), perhaps due to their dependence on warm soils for metabolism of stored root carbohydrates. Second-year aspen response pattern was intermediate. In all regressions, maximum growth was in the range of 100 to 200 Langleys per day and about 1.5 mm daily evaporation.

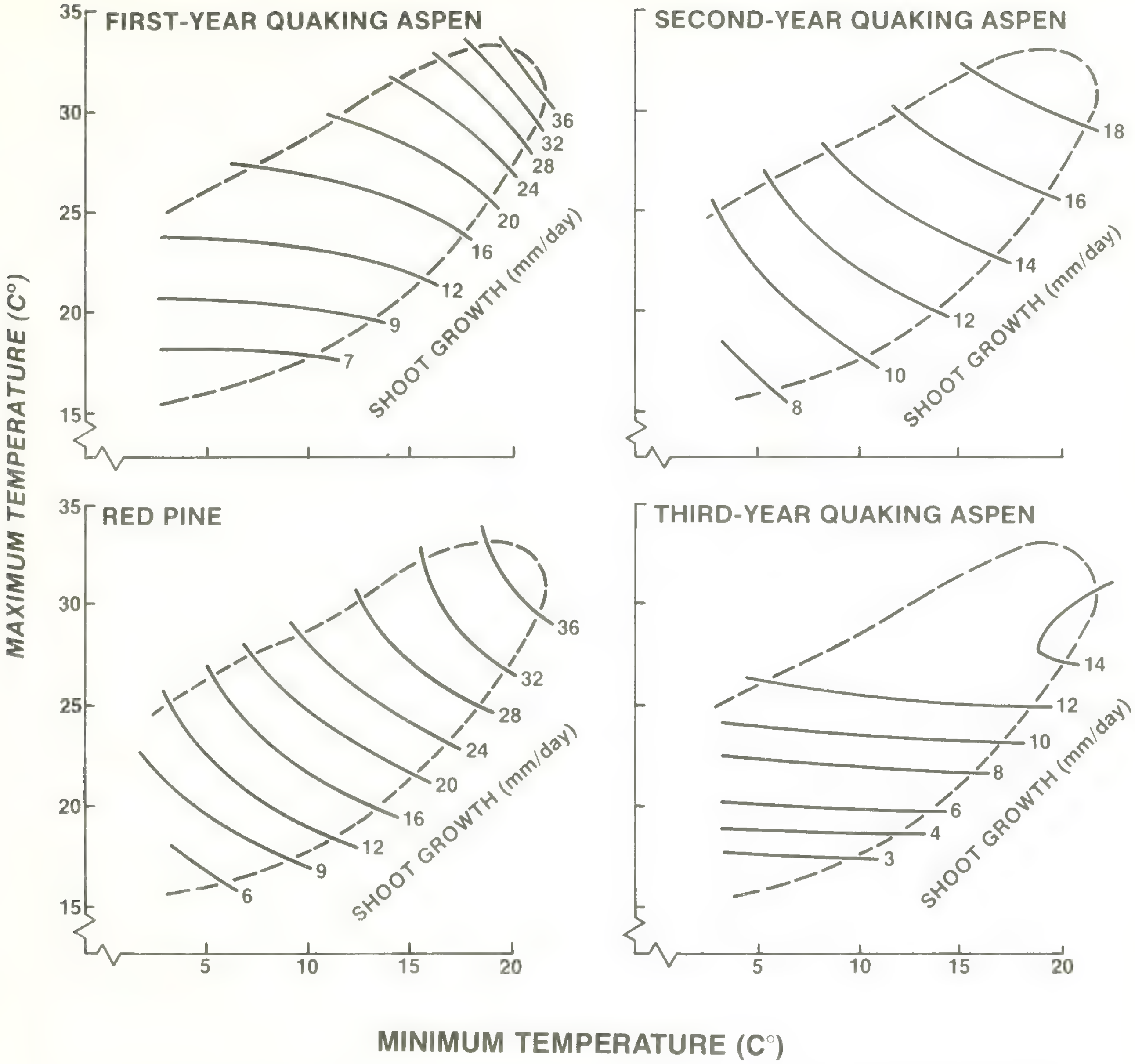

Figure 2.—*Diurnal shoot growth of red pine and quaking aspen in response to daily maximum and minimum air temperatures. The dashed curve encloses the range of observed temperature combinations.*

Cremer (1976) attributes decreased growth of giant eucalyptus, *Eucalyptus regnans* F. Muell., and especially monterey pine, *Pinus radiata* D. Don, on hot sunny days at least in part to shrinkage due to dehydration caused by high evaporative demand. The rate of shrinkage was greatest before noon and caused an early afternoon depression in measured shoot length. He found no mid-day depression on rainy days. Milne *et al.* (1977) observed similar shrinkage in Sitka spruce, *Picea sitchensis* (Bong.) Carr. Such shrinkage is reversible overnight. It is questionable whether we would have found such large shoot growth responses to E and the growth anomaly at high E and W if we would have taken the measurements early in the morning.

ln DAYS and Dummy Variables

ln DAYS served three purposes: to account for variations in length of measurement period; to evaluate the effect of handling growing shoots; and to evaluate the suitability of long remeasurement periods

Table 4.—*Simple correlation matrix between independent and dependent variables in the ln form*

	Independent variables							**Dependent variables (ΔS)**			
								P. tremuloides			***P. resinosa***
Independent variable	**Tmax**	**Tmin**	**M**	**Wo**	**W-1**	**E**	**Sc/Sf**	**Year 1**	**Year 2**	**Year 3**	**13 & 14 years**
	Correlation coefficients[1]										
Tmax	1	0.61	−0.61	0.51	0.52	0.63	0.31	0.86	0.71	0.70	0.42
Tmin		1	−.01	−.03	.01	.06	.40	.62	.59	.40	.63
M			1	−.06	−.05	−.06	.18	.01	.11	−.22	−.05
Wo				1	.74	.97	.21	.14	.34	.36	−.03
W-1					1	.79	.19	.17	.53	.69	.32
E						1	.22	.31	.42	.40	.05
Sc/Sf							1	.02	.50	.22	.12

[1] Coefficients between independent variables are for years 1977-1979 combined.

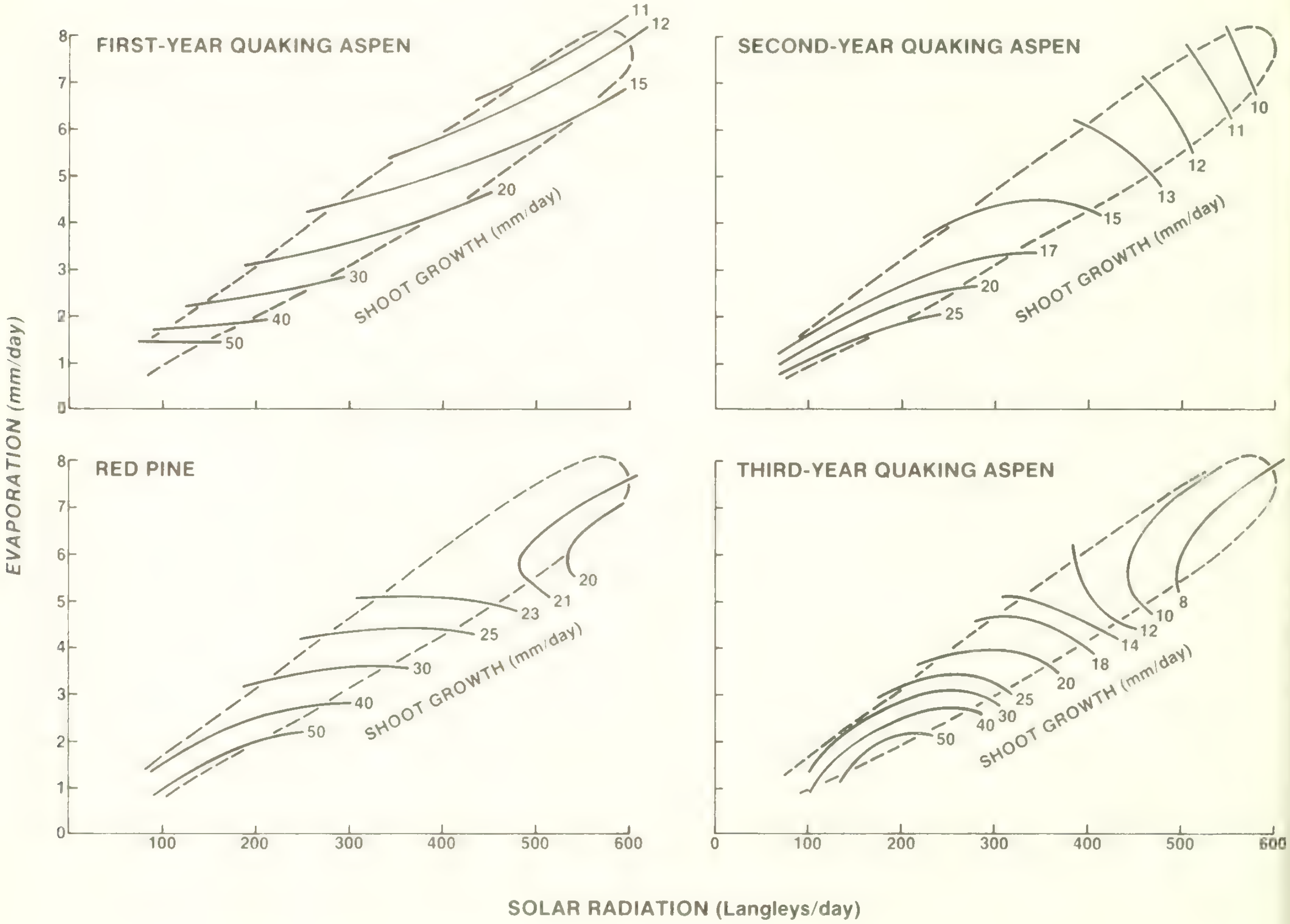

Figure 3.—*Diurnal shoot growth of red pine and quaking aspen in response to free surface evaporation and current-day incoming solar radiation. The dashed curve encloses the range of observed independent variable combinations.*

for growth analyses. The first purpose could have been met just as well with ln (ΔS/DAYS) as the dependent variable.

Shoot growth apparently was not altered by handling because the coefficients for ln DAYS for three of the four regressions were not significantly different from 1 (table 5). A coefficient significantly greater than 1 would be interpreted as a reduction in growth due to handling assuming shoots would recover from handling disturbance during longer measurement periods. Coefficients less than 1 would indicate a stimulus by handling.

The significant coefficient for ln DAYS for first-year aspen means that long measurement periods are less suitable than short periods for analysis. (Handling effects can be ruled out because these aspens had the longest remeasurement intervals.) A wide range in DAYS tends to increase its significance as a predictor variable at the expense of other variables. Extreme observations are diminished in averages, narrowing the statistically useful range of variation. The constant for this regression has been adjusted for mean DAYS by adding the contribution for the mean ln DAYS term (table 3).

The dummy variables showed that red pine grew nearly 10 percent more in year 13 and that groups of pine and aspen differed in growth by about 5 and 8 percent, respectively (table 5). This much intraspecific and inter-year variability is common.

CONCLUSIONS

This study demonstrated that sufficiently accurate measures of shoot growth can be easily taken and quantitatively related to meteorological variation. The equations are credible because they were derived independently and because they depict growth generally consistent with expected plant-environment interaction. Some weaknesses in method disclosed by the analysis are not insurmountable. Empirical shoot growth models integrate a number of competing and complementary processes whose net sum is expressed as growth, and so they do not provide much insight into the complexity of plant-environment interaction. On the other hand, their simplicity and adaptability to application are critical to their usefulness.

NEEDS AND RECOMMENDATIONS

The greatest need for improvement is in estimating the water balance. Zahner (1967) showed that soil moisture under forest cover could be accurately estimated according to Thornthwaite and Mather (1955) in soils with good internal drainage. The problem is to estimate the volume of soil exploited by roots, the amount of water available to plants in that volume, the relative importance of each textural horizon, and the amount of water evapotranspired. These will vary with species and the age of the stand. Crop/age water use coefficients could be determined empirically with concurrent instrumentation of soil moisture.

Thornthwaite and Mather's (1955) calculation of soil moisture depends on estimates of evapotranspiration based on air temperature. Their method has a distinct advantage because it is easy to apply and temperature is the most common meteorological information available. On the other hand, evapotranspiration is more properly estimated from solar

Table 5.—*Additional equation coefficients for terms needed for analysis but not for predicting shoot growth (t-value in parentheses)*

Independent variable	Aspen			Red pine
	Year 1	Year 2	Year 3	Years 13 and 14
	Coefficients[1]			
Year Dummy	—	—	—	1.097(1.94)[2]
Group Dummy	—	1.076(1.77)	—	1.052(1.06)
1n DAYS[3]	1.155(2.52)	1.014(0.35)	1.004(0.09)	1.000(0.00)

[1] Dummy coefficients are in arithmetic units and are interpreted as a ratio of the greater over the lesser.

[2] Year 13 greater than year 14 (by 10 percent).

[3] Average DAYS are 4.06, 2.34, 1.51, and 1.74, respectively. t-values are computed as deviation from 1.000

radiation and evaporative power of the air (Eq. 1). The modified Penman approach (Gray *et al.* 1970) should be evaluated to determine if significantly improved estimates of evapotranspiration and therefore soil moisture are possible.

Small but significant improvements should be made in shoot growth measurement procedures. Remeasurement should be near sunrise to eliminate the problems of diurnal shrinkage (Cremer 1976, Milne *et al.* 1977). At 45° N latitude, less than 3 percent of a clear June day's solar radiation is elapsed by 0800 hours local daylight savings time (0700 hours local standard time), so the need to partition data associated with the solar day is eliminated. Measurement intervals should seldom exceed one day, both to gain advantage of data extremes and to provide as many observations as possible. Measurement precision could be improved to ± 0.1 mm (at least for pines) by setting a reference pin in the lower stem and by using a vernier scale (Farnsworth 1955, Hari and Leikola 1974). Automatic recorders (Milne *et al.* 1977) would be ideal but not necessary. Ten to 20 trees should be measured, both to assure a complete seasonal data base and to minimize measurement errors by averaging.

Excising and weighing a thermograph trace would provide reasonably fast and highly accurate expressions of mean temperatures or hourly temperature sums. Temperature sums have been useful in predicting shoot growth in other studies (Hari and Leikola 1974).

Nonlinear and dynamic (Hari and Leikola 1974) models should be tested in future modeling efforts. Models fitted around the concept of leaf temperature/transpiration relations (Idso *et al.* 1966) need to be explored. Certainly the biggest need is for long term regional growth data for a wide range of climates, soils, species, and ages.

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Perala, Donald A.
Modeling aspen and red pine shoot growth to daily weather variations. Res. Pap. NC-236. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 11 p.

Quantifies daily shoot growth of quaking aspen and red pine in response to daily variation in air temperature, soil moisture, solar radiation, evapotranspiration, and inherent seasonal plant growth rhythm. Discusses potential application of shoot growth equations to silvicultural problems related to microclimatic variation. Identifies limitations and areas for improvement.

KEY WORDS: *Populus tremuloides, Pinus resinosa,* air-temperature, soil-moisture, solar-radiation, evapotranspiration.

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The Economics of a Mechanized Multiproduct Harvesting System for Stand Conversion of Northern Hardwoods

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John A. Sturos, Robert M. Barron, Edwin S. Miyata, and Helmuth M. Steinhilb

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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THE ECONOMICS OF A MECHANIZED MULTIPRODUCT HARVESTING SYSTEM FOR STAND CONVERSION OF NORTHERN HARDWOODS

John A. Sturos, *Research Mechanical Engineer,*
Edwin S. Miyata, *Research Industrial Engineer,*
Helmuth M. Steinhilb, *Research Forester,*
Houghton, Michigan,
and **Robert M. Barron,** *Research Assistant,*
Department of Forestry,
Michigan Technological University,
Houghton, Michigan,

To minimize the impact of raw material shortages and escalating softwood stumpage prices, many forest products companies are revising their forest management techniques and objectives as well as their wood harvesting practices. Two methods being considered to substantially increase raw material availability for the wood industry are:

- Conversion of understocked or poor-quality hardwood stands to more productive conifer species.
- Increased recovery and utilization of logging residue.

The need for stand conversion operations in northern hardwoods results from past timber harvesting practices that effectively replaced large acreages of productive conifer species or high-quality northern hardwoods with low-quality hardwoods (Cook 1955). This represents a very serious problem in terms of the earnings potential of such timberland regardless of the intended product.

Although the technology of converting northern hardwoods is very limited, much can be learned from past experiences in other regions. Current practices in the Southeast (Peevy and Brady 1972) and the Pacific Northwest (Yoho *et al.* 1969, Dimock *et al.* 1976) indicate that forest productivity can be increased significantly by using regionally proven and accepted stand conversion practices. Presently the capital outlays for conversion operations are extremely high because of the great expense of initial site preparation. These costs are a function of the removal method, the condition, and the disposal of the existing stand.

The existing stand can be removed from the intended conversion site by either destroying it or harvesting it. Destroying unwanted vegetation represents a large direct cost with no offsetting returns, but harvesting the same vegetation may lower the investment and enhance the profitability of stand conversion (Anderson 1974). Peevy and Brady (1972) report that removal of the old stand accounts for half or more of the costs incurred in stand conversion programs.

Stand conversion operations provide an opportunity to recover large quantities of woody material. Lowe (1973) reports that only 60 to 65 percent of the tree's total fiber leaves the forest under conventional sawtimber and pulpwood logging operations. Mattson and Carpenter (1976), in a case study of a northern hardwood timber sale, determined that 41 percent of the tree weight above the stump was left in the woods from sawtimber-size trees and 49 percent was left from poletimber trees.

Any stand conversion program for the Lake States region should be directed at minimizing the costs of removing the existing timber stand while maximizing the recovery of wood products and residues. Whole-tree harvesting with saw log sorting may provide an economical way to achieve these objectives. A mechanized multiproduct harvesting system would:

1. Minimize site preparation costs through the harvesting of existing timber.
2. Recover additional supplies of fiber and/or fuelwood through the removal of logging residues and small diameter standing timber.

3. Recover high-quality sawtimber from predominantly pole-size hardwood stands.
4. Create obstruction-free planting sites, thus facilitating machine planting.

This paper presents the results of a study that evaluated the economic feasibility of clear-felling several diameter northern hardwood stands in an effort to create debris-free planting sites while maximizing raw material recovery. Several methods were investigated in combining the saw log recovery with whole-tree and residue chipping.

The harvesting operations studied were part of a U.S. Department of Energy funded study, "Application of Sugar Maple and Black Locust to the Biomass/Energy Plantation Concept," being carried out by the Department of Forestry, Michigan Technological University, Houghton, Michigan.

STAND DESCRIPTION

The study area comprised approximately 50 acres of predominantly pole-size northern hardwoods located in the Copper Country State Forest[1] in Michigan's Upper Peninsula. The topography was flat, with only about a 20-foot difference in elevation throughout the proposed study area. The soil was a sandy loam. The area contained usable logging roads and was bordered on the south by a blacktop highway (fig. 1).

The area was divided into a 20-acre block in Section 35 (Site 35) and a 32-acre block in Section 36 (Site 36). Site 35 was of low quality consisting primarily of pole-size trees ranging from 1- to 12-inches d.b.h. and did not produce any saw logs. A preliminary survey indicated 807 stems per acre with a basal area of 116 square feet per acre (table 1). The estimated biomass on Site 35 was 102 green tons per acre.

Site 36 consisted of higher quality trees and was divided into three smaller blocks (Sites 36 A, B, and C) where several integrated harvesting methods were evaluated. Sites 36 A, B, and C were approximately 13, 8, and 11 acres, respectively, and contained, on a per acre basis, 531 to 626 stems, 124 to 139 square feet of basal area, and 118 to 137 green tons of biomass. Trees ranged from 1- to 20- inches d.b.h.

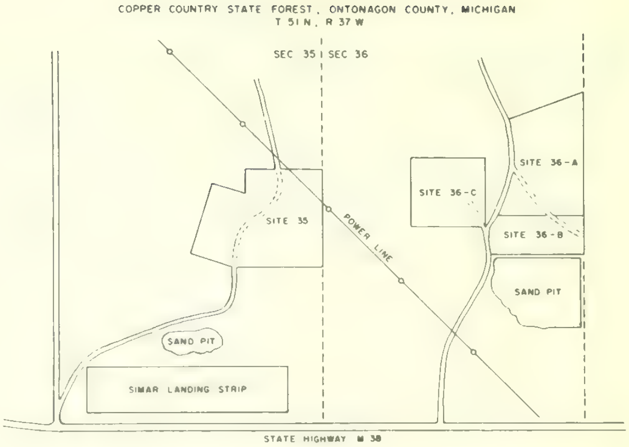

Figure 1.—*Map of the four logging sites.*

METHODS

The 52-acre study area consisted of four separate study sites (Sites 35 and 36 A, B, and C). Each site was clearcut down to a 2-inch diameter by a different logging system. The major difference in logging methods was in the way whole-tree chipping was integrated with saw log removal.

Because Site 35 did not contain any saw log trees, a standard whole-tree chipping system was used to clearcut the site. The chips were sold to a pulp mill 22 miles from Site 35. The mill required that all trees be chain flailed to remove most of the twigs and small branches before chipping.

The feller/bunchers felled the trees and placed them on the ground in optimum size bunches with all the butts facing toward a central landing site (fig. 2). A grapple skidder transported the bunches from the felling area to the landing. After dropping the skid load at the landing for chain flail delimbing, the skidder operator picked up a grapple load of delimbed trees and shuttle-skidded them a short distance to the chipper where they were chipped. The chips were blown into chip vans and transported to the mill.

On Site 36 A, the same whole-tree harvesting and chipping equipment was used plus one saw log trailer with loader, one sawyer to fell the saw log trees, and one sawyer to cut saw logs from full trees skidded to the side of the saw log trailer. The loader was placed parallel to and about 20 feet to one side of the chipper (fig. 3). Its function was to lift and deck

---

[1] *Provided by the Michigan Department of Natural Resources on the east half of Section 35 and the west half of Section 36, T51N, R37W, Ontonagon County. The State of Michigan Department of Natural Resources and Michigan Technological University, Department of Forestry, cooperated in this study with the North Central Forest Experiment Station.*

Table 1. —*Stocking table for all species combined (per acre basis)*[1]

Study area	**Diameter distribution (d.b.h. inches)**										
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**Totals**
Site No. 35											
Stems per acre	169	306	232	83	15	2	—	—	—	—	807
Basal area (sq. ft.)	3.4	27.5	46.4	29.0	8.2	1.6	—	—	—	—	116.1
Estimated biomass[2] (green tons)	1.9	19.4	42.0	28.3	8.6	1.7	—	—	—	—	101.9
Site No. 36A											
Stems per acre	193	107	93	81	59	23	11	6	2	2	577
Basal area (sq. ft.)	3.9	9.6	18.8	28.4	32.4	18.2	11.8	8.4	3.5	4.4	139.4
Estimated biomass[2] (green tons)	2.2	6.8	16.9	27.6	33.9	19.2	12.8	9.1	3.8	4.7	137.0
Site No. 36B											
Stems per acre	195	139	128	94	45	15	7	1	2	—	626
Basal area (sq. ft.)	3.9	12.5	25.6	32.9	24.8	11.8	7.5	1.4	3.5	—	123.9
Estimated biomass[2] (green tons)	2.3	8.8	23.2	32.0	25.9	12.5	8.2	1.5	3.8	—	118.2
Site No. 36C											
Stems per acre	150	120	114	69	33	24	11	6	3	1	531
Basal area (sq. ft.)	3.0	10.8	22.8	24.2	17.8	18.8	11.8	8.4	5.3	2.2	125.1
Estimated biomass[2] (green tons)	1.7	7.7	20.6	23.5	19.0	20.0	12.8	9.1	5.7	2.4	122.5

[1] Stocking and yield estimates based on a 25-percent cruise of each stand.
[2] Includes saw log weights.

the bucked-out saw logs. The loader also sorted cut tops, branches, culls, and smaller diameter trees contained in that skid load, placing them next to the chipper for chipping. The logs were sold to a commercial sawmill that picked up the decked logs on site.

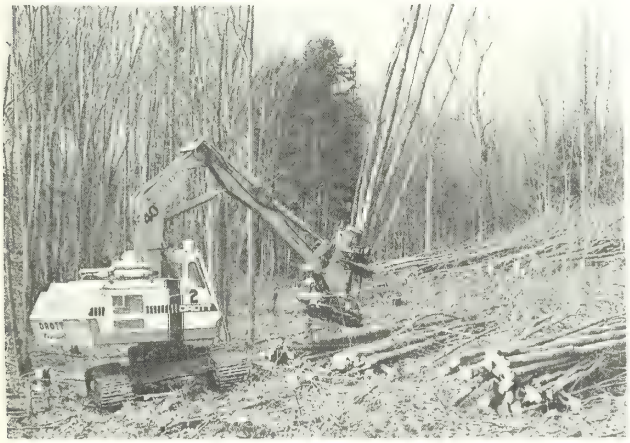

Figure 2.—*The Drott*[3] *feller/buncher was used to fell and bunch all pulpwood size trees.*

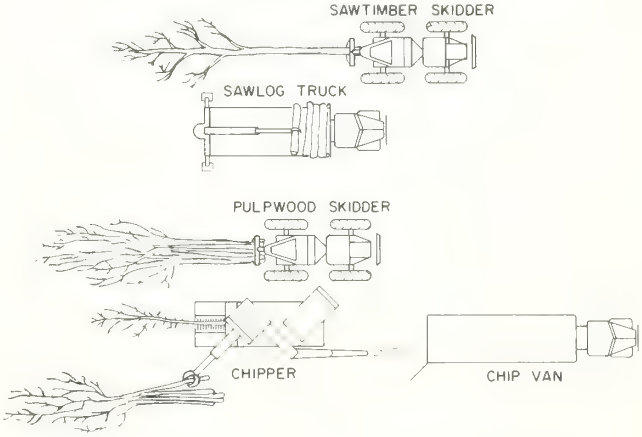

Figure 3.—*Plan view of the equipment layout at the landing for integrated harvesting of Site 36A.*

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[3] *The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.*

On Site 36B, all non-saw log trees were mechanically felled, bunched, chain flailed, skidded, and chipped first, leaving the saw log trees standing. The sawyer then felled and bucked the saw log trees at the stump. A forwarder prehauled the bucked logs to the roadside. The topwood was then skidded and chipped separately.

On Site 36C, the saw log trees were felled and bucked at the stump first. The remaining trees were felled mechanically and bunched with the tops from the saw log trees. The bunches were then chain flailed, skidded, and chipped. The forwarder then picked up the saw logs and prehauled them to the roadside.

All operations during the study were observed, sampled, and recorded to determine productivity and operating costs. The data included time, motion, and delay data of the feller bunchers, skidders, chain flail, chipper, saw log trailer loader, and the sawyer felling saw log trees and bucking saw logs at the landing. Additional data included trucking time and distance; weight of chips produced; and the number, grade, and board feet of saw logs removed.

YIELDS OF CHIPS AND SAWTIMBER

The chip yields from the near-complete harvest (2-inch d.b.h. and larger) of the 20-acre poletimber stand (Site 35) was 1,479 tons or 74 tons per acre (table 2). The three saw log sites produced 2,948 tons of chips plus 53,035 board feet of saw logs. Site 36A produced the most tonnage of biomass on a per acre basis including chips and saw logs (114 tons per acre) and Site 36B produced the least (80 tons per acre). But Site 36 B produced the highest volume of saw logs on a per acre basis (1,943 board feet per acre). The averages for the three saw log sites on a per acre basis were 91 tons of chips and 1,646 board feet of saw logs, or 101 tons of chips and saw logs.

The saw logs produced came from five species: sugar maple, red maple, black cherry, red oak, and yellow birch. They were graded as either veneer, No. 2, or No. 3 saw logs; the value ranged from $340 per thousand board feet for yellow birch veneer to $90 per thousand board feet for all No. 3 saw logs (table 3). The total value of saw logs produced was $7,690. The veneer was 20 percent of the total saw log volume, but it was worth 41 percent of total saw log value. Half of the remaining saw logs were No. 2 logs; the other half were No. 3 logs.

CHIP PRODUCTION COSTS

The costs associated with the chipping and saw log operations were calculated on the basis of scheduled and productive hours of the equipment and sawyer (Miyata 1980, Miyata and Steinhilb 1981). Table 4 lists the equipment including the purchase price and other assumptions used in determining the fixed and operating costs for each machine (Miyata *et al.* 1981).

The costs of producing chips were greater with all three integrated chip-saw-log operations (Sites 36 A, B, and C) than with the conventional whole-tree chipping operation on the poletimber stand (Site 35) (table 5). The logging costs, excluding overhead and stumpage, ranged from $8.66 per green ton for the chips-only operation to $9.87 per green ton on Site 36C where the saw log trees were felled and bucked before whole-tree harvesting of all remaining trees 2 inches d.b.h. and larger. The most efficient integrated operation was on Site 36A ($9.20 per green ton) where the saw log trees were skidded along with the smaller trees to the landing to be sorted and bucked. If we add 15 percent for overhead costs and $1.20 per ton for stumpage, the chip production costs range from $11.16 per green ton to $12.55 per green ton.

Table 2.—*Chip and sawtimber yields from the four study areas*

Study area	Acreage	Chips	Saw logs		Total	Chips	Chips and saw logs	Board feet/acre
	Acres	*Tons*	*Bd ft*	-------- *Tons* --------		---- *Tons/acre* ----		
Poletimber site 35	20.05	1,479.46	—	—	1,479.46	73.79	73.79	
Saw log site 36A	13.69	1,455.03	18,270	109.62[1]	1,564.65	106.28	114.29	1,335
Saw log site 36B	7.76	534.21	15,075	90.45[1]	624.66	68.84	80.50	1,943
Saw log site 36C	10.78	958.34	19,690	118.14[1]	1,076.48	88.90	99.98	1,827
Total for saw log sites	32.23	2,947.58	53,035	318.21	3,265.79	91.45[2]	101.33[2]	1,646[2]

[1] Assumed 6 tons/Mbf. Unpublished data by H. M. Steinhilb.

[2] Average of the three saw log sites.

Table 3.—*Amount, grade, and value of saw logs produced from the three sites*

		Logging sites					
		36A		36B		36C	
Saw log grade	**Range of saw log values[1]**	**Amount**	**Value**	**Amount**	**Value**	**Amount**	**Value**
	Dollars[2]/Mbf	*Bd ft*	*Dollars*	*Bd ft*	*Dollars*	*Bd ft*	*Dollars*
Veneer	190–340	5,010	1,457.50	2,560	762.60	3,325	918.85
Number 2 logs	110–145	7,480	948.15	5,495	691.25	7,900	997.80
Number 3 logs	90	5,780	520.20	7,020	631.80	8,465	761.85
TOTAL		18,270	2,925.85	15,075	2,085.65	19,690	2,678.50

[1] Due to variation with species.

[2] 1980 U.S. dollars.

A breakdown of the costs for producing chips indicates that felling and transport account for 47 to 60 percent of the total cost for the four logging operations (table 5). Chain flail costs range from $0.83 to $1.15 per ton or 9 to 12 percent of the total cost. Refer to tables 8-11 in the Appendix for more detailed chip production cost analyses.

SAW LOG PRODUCTION COSTS

The most efficient saw log operation was on Site 36B where all the non-saw log trees were harvested first; then a sawyer felled and bucked the saw log trees, and the saw logs were then prehauled by a forwarder to roadside (fig. 4). The range in saw log production costs (excluding overhead and stumpage)

Table 4.—*Equipment costs and cost assumptions[1]*

Equipment	**Purchase cost**	**Economic life**	**Scheduled hours/year**	**Utilization**	**Productive hours/year**	**Repair cost multiplier[3]**	**Machine rate/hr without labor[5]**	
							Fixed	**Operating**
	Dollars[2]	*Years*	*Hours*	*Percent*	*Hours*		*Dollars*	*Dollars[6]*
2 Drott feller-bunchers 40 LC ($139,000 ea.)	278,000	5	2,250	65	1,463	100[4]	32.38	24.18
1 John Deere grapple skidder 740	95,000	3	2,000	67	1,360	60[4]	27.31	20.87
1 Morbark Chiparvester, 22"	152,500	5	2,000	75	1,500	60[4]	30.38	20.60
1 Pettibone Chain Flail PM 850	90,000	5	2,000	80	1,600	60	21.20	13.16
1 Caterpillar Dozer D7G	150,000	5	1,000	80	800	100[4]	37.85	28.07
1 fuel truck	2,000	5	2,000	40	800	100	.55	2.50
1 maintenance van	2,000	5	2,000	—	—	5	.28/SH[7]	.02/mi.
4 truck tractors @ 45,000 ea.	180,000	5	40,000 mi.	—	—	50	.37/mi.	.39/mi.
13 chip vans @ 12,000 ea.	156,000	8	20,000 mi.	—	—	10	.12/mi.	.06/mi.
Total cost	1,105,500							

[1] Assumes 15 percent interest rate, 3 percent insurance rate, and 3 percent tax rate. (2 percent is insurance and tax rate on maintenance van and fuel truck).

[2] 1980 U.S. dollars

[3] The percentage rate by which the hourly depreciation is multiplied to estimate hourly repair costs.

[4] Warren, B. Jack. 1977. Logging cost and production analysis. Timber Harvesting Report No. 4, p. 42. LSU/MSU Logging and Forestry Operation Center, Bay St. Louis, Mississippi.

[5] Based on productive hours.

[6] Fuel cost at $1.00 per gallon.

[7] SH = scheduled hour.

Table 5.—*Breakdown of costs for producing chips*[1]

	Logging site							
Operation	**35**		**36A**		**36B**		**36C**	
	Dollars[2]/ton[3]	*Percent*	*Dollars/ton[4]*	*Percent*	*Dollars/ton[5]*	*Percent*	*Dollars/ton[6]*	*Percent*
Feller/buncher	2.86	33.0	1.63	17.7	3.26	33.3	2.55	25.9
Skidder	1.18	13.6	2.25	24.5	1.91	19.5	1.55	15.7
Chipper	1.19	13.8	1.28	13.9	1.16	11.8	1.52	15.4
Chain flail	.84	9.7	.85	9.2	.83	8.5	1.15	11.7
Transportation	2.37	27.3	2.68	29.2	2.42	24.8	2.81	28.4
Other	.22	2.6	.51	5.5	.21	2.1	.29	2.9
Subtotal	8.66	100.0	9.20	100.0	9.79	100.0	9.87	100.0
Overhead (15 percent)	1.30		1.38		1.47		1.48	
Stumpage	1.20		1.20		1.20		1.20	
TOTAL COST	11.16		11.78		12.46		12.55	

[1] Refer to tables 8-11 in Appendix for detailed chip production cost tables.
[2] 1980 U.S. dollars.
[3] Based on 1479.46 tons of chips produced.
[4] Based on 1455.03 tons of chips produced.
[5] Based on 534.21 tons of chips produced.
[6] Based on 958.34 tons of chips produced.

for the three sites was $46.30 (Site 36B) to $84.22 per thousand board feet (Site 36C) (table 6). Refer to the Appendix for more detailed saw log production cost tables (tables 12-14). Adding an overhead cost of 15 percent and a stumpage of $60 per thousand board feet gives an estimated total saw log production cost range of $113.24 to $156.85 per thousand board feet.

A breakdown of the saw log costs indicates that the chain saw felling, limbing, and bucking costs, ranging from 46 to 52 percent of the total cost, were most efficient on Site 36B ($21.23/Mbf) where all the non-saw log trees were harvested first. These costs on Site 36B were less than half of the felling, limbing, and bucking costs for Site 36C ($44.19/Mbf). On the other hand, the most efficient method of transporting saw logs from the stump to the landing was by whole-tree skidding before bucking (Site 36A–$13.56/Mbf). Grapple skidding of saw logs on Site 36C was very inefficient ($45.75/Mbf). The saw log trailer with loader greatly increased the saw log production cost for Site 36A primarily because of the low utilization (41 percent).

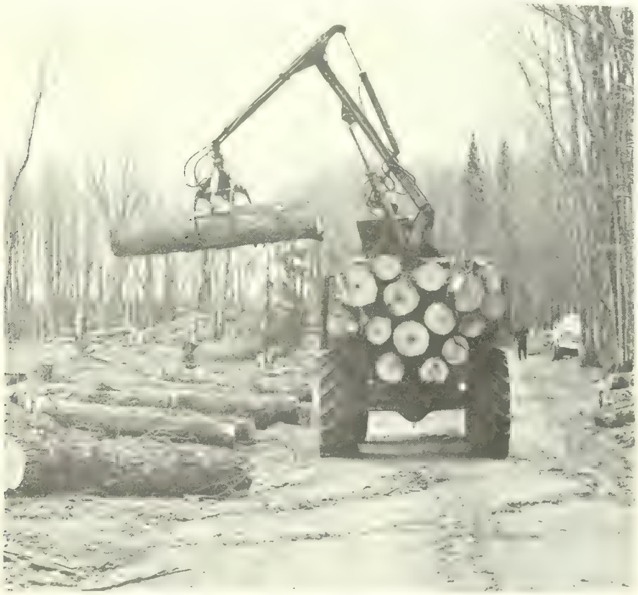

Figure 4.—*Forwarder unloading saw logs from Site 36B along main haul road.*

PROFIT POTENTIAL[2]

The conventional whole-tree chipping operation on the poletimber site (Site 35) produced 1,479 tons of whole-tree chips at an estimated cost of $11.16 per green ton. If we assume a realistic value of $13.50 per green ton for the chips, this logging method yielded an estimated profit of $2.34 per green ton or $173 per acre.

For the integrated harvesting operations on saw log sites 36 A, B, and C, we calculated the potential profits generated from chips and saw logs and from the alternative of chipping everything including saw logs (table 7).

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[2] *All estimated profit values discussed are estimated value before income tax.*

Table 6.—*Breakdown of costs for producing saw logs*[1]

Operation	36A		36B		36C	
	Dollars[2]/Mbf[3]	*Percent*	*Dollars/Mbf[4]*	*Percent*	*Dollars/Mbf[5]*	*Percent*
Sawyer (felling, limbing, bucking)	32.29	45.9	21.23	45.9	44.19	52.5
Skidder	13.56	19.3	—	—	45.75[6]	36.3
Forwarder	—	—	25.07	54.1	28.53[7]	11.2
Saw log trailer With loader)	24.53	34.8	—	—	—	—
Subtotal	70.38	100.0	46.30	100.0	84.22[5]	100.0
Overhead (15 percent)	10.56		6.94		12.63	
Stumpage	60.00		60.00		60.00	
TOTAL COST	140.94		113.24		156.85	

[1] Refer to tables 12-14 in Appendix for detailed saw log production cost tables.

[2] 1980 U.S. dollars.

[3] Based on 18.27 Mbf of saw logs produced.

[4] Based on 15.075 Mbf of saw logs produced.

[5] Based on 19.69 Mbf of saw logs produced.

[6] Based on 13.155 Mbf of saw logs skidded.

[7] Based on 6.535 Mbf of saw logs forwarded.

The potential profit generated by producing chips ranged from $1.72 per green ton on Site 36A to $0.95 per green ton on Site 36C. The profit per acre extended from $183 per acre on Site 36A to $72 per acre on Site 36B.

The estimated saw log production profits were $19, $25, and $-21 per thousand board feet ($26, $49, and $-38 per acre) on Sites 36 A, B, and C, respectively, based on the saw log revenue values listed in table 3.

Summing the profits generated by chips and saw logs and comparing the sum to the profits by chipping everything gives the following percentage of increase or decrease in profits with saw logs: 6-percent increase on Site 36A; 44-percent increase on Site 36B; and 51-percent decrease on Site 36C.

Table 7.—*Projected profit before income tax from producing chips and saw logs and from the alternative of chipping the total biomass including saw logs*

SAW LOG SITE 36A (13.69 ACRES)

Product	Total yield		Cost/unit		Total cost	Total revenue	Profit	Profit/acre	Profit/ton	Profit/Mbf
	Tons	*Mbf*	*Dollars/ton*[1]	*Dollars/Mbf*	*Dollars*	*Dollars*	*Dollars*	*Dollars/acre*	*Dollars/ton*	*Dollars/Mbf*
Chips	1,455.03		11.78		17,140	19,643	2,503	183	1.72	
Saw logs		18.270		140.94	2,575	2,926	351	26		19
Chips only	1,564.65		11.78		18,432	21,123	2,691	197	1.72	
SAW LOG SITE 36B (7.76 ACRES)										
Chips	534.21		12.46		6,656	7,212	556	72	1.04	
Saw logs		15.075		113.24	1,707	2,086	379	49		25
Chips only	624.66		12.46		7,783	8,433	650	84	1.04	
SAW LOG SITE 36C (10.78 ACRES)										
Chips	958.34		12.55		12,027	12,938	911	84	0.95	
Saw logs		19.690		156.85	3,088	2,678	-410	– 38		-21
Chips only	1,076.48		12.55		13,510	14,532	1,022	95	0.95	

[1] 1980 U.S. dollars.

DISCUSSION

In an integrated saw log-chip logging operation, one of the most important objectives is to sort out saw logs without decreasing chipper productivity. In comparing the operations on Sites 36A (sorting at landing) and 36B (sorting at stump), chipper productivity on Site 36A decreased 14 percent based on scheduled hours (38.3 tons/hr on Site 36A versus 44.5 tons/hr on Site 36B), and it decreased 8 percent based on productive hours (50.2 tons/hr versus 54.5 tons/hr). This decreased chipper productivity increased chipping costs about 10 percent ($1.28 on for Site 36A versus $1.16 on for Site 36B).

Time study data collected on the saw log trailer with loader used on Site 36A indicated that 17 percent of the loader's time was used in moving the tops from the saw log trees to the chipper. Therefore, the saw log trailer's total cost was allocated 17 percent to the production of chips and 83 percent to the production of saw logs.

Some of the difference between the estimated standing biomass given in table 1 and the actual recovered tonnage given in table 2 can be partially accounted for by the reduction in biomass by chain flailing, loss of some stems during skidding, and the failure to harvest all of the small trees.

The results presented in this paper are for specific case studies and do not imply long-term averages. Factors that affect productivity were not constant from one logging method (or site) to another. These factors include, but are not limited to, stand characteristics, plot size, skidding or forwarding distances, operator ability, weather, and unavoidable delays. Therefore, the results should be regarded as exemplary.

SUMMARY

This study has investigated the economics of clearcutting both a northern hardwood poletimber stand by a conventional whole-tree harvesting system and a sawtimber stand by several combinations of whole-tree chipping and saw log recovery. The conventional whole-tree harvesting of the poletimber stand yielded a projected profit of $2.34 per green ton before taxes or $173 per acre. The most profitable integrated harvesting method involved using the whole-tree chipper at the landing simultaneously with the saw log recovery system. Saw log trees and non-saw log trees were skidded to the landing together and then sorted. This method yielded a potential profit of $209 per acre, including profits of $1.72 per green ton generated by the production of 1,455 tons of chips and $19 per thousand board feet generated by the production of 18,270 board feet of saw logs.

Multiproduct recovery should be emphasized in future stand conversion operations to obtain the highest value end use of the standing timber and thereby minimize total conversion costs. Utilization of whole trees and forest residuals will increase in the future because of the changing combination of solid wood, fiber, and energy products demanded from the forest.

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APPENDIX

Table 8.—*Harvesting and transportation costs for producing chips on site 35 based on productive hours*

Operation	Time on job		Machine rate F	Machine rate O	Total fixed cost	Total operating cost	Total labor cost[4]	Total cost	Cost per ton[5]	Total cost
	SH[1]	*PH*[2]	*Dollars*[3]							*Percent*
Feller/buncher	73	62.0	32.38	24.18	2,007.56	1,499.16	730	4,236.72	2.86	33.0
Skidder	34	29.1	27.31	20.87	794.72	607.32	340	1,742.04	1.18	13.6
Chipper	34	27.8	30.38	20.60	844.56	572.68	340	1,757.24	1.19	13.8
Chain flail	34	27.6	21.20	13.16	585.12	363.22	303	1,251.34	0.84	9.7
Trucks[6]	—	—	.37/mi	.39/mi	846.56	892.32	1,360	3,098.88	2.09	24.1
Chip vans[6]	—	—	.12/mi	.06/mi	274.56	137.28	—	411.84	0.28	3.2
Maintenance van[7]	34	—	.28/SH	.02/mi	9.52	0.88	—	10.40	0.01	0.1
Fuel truck[8]	34	13.6	0.55	2.50	7.48	34.00	—	41.48	0.03	0.4
Dozer[9]	34	3.4	37.85	28.07	128.69	95.44	37	261.13	0.18	2.1
TOTAL					5,498.77	4,202.30	3,110	12,811.07	8.66	100.0

[1] SH = scheduled hours.

[2] PH = productive hours.

[3] 1980 U.S. dollars.

[4] Labor cost = $10.00/hr for each operator including all fringe benefits.

[5] Cost per ton based on 1479.46 tons of chips produced.

[6] Hauling distance = 22 miles (one way) and 52 van loads.

[7] Fixed cost = $0.28/SH x 34 SH = $9.52. Operating cost = $0.02/mi x 44 mi = $0.88.

[8] Assumed 40-percent utilization.

[9] Assumed 10-percent utilization.

Table 9.—*Harvesting and transportation costs for producing chips on site 36A based on productive hours*

Operation	**Time on job**		**Machine rate F**	**O**	**Total fixed cost**	**Total operating cost**	**Total labor cost[4]**	**Total cost**	**Cost per ton[5]**	**Total cost**
	SH[1]	*PH[2]*	*Dollars[3]*							*Percent*
Feller/buncher	43	34.3	32.38	24.18	1,110.63	829.37	430.00	2,370.00	1.63	17.7
Skidder[11]	72.5	52.8	27.31	20.87	1,441.97	1,101.94	725.00	3,268.91	2.25	24.5
Chipper	38	29.0	30.38	20.60	881.02	597.40	380.00	1,858.42	1.28	13.9
Chain flail	38	27.3	21.20	13.16	578.76	359.27	304.00[12]	1,242.03	.85	9.2
Trucks[6]			.37/mi	.39/mi	941.28	992.16	1,520.00	3,453.44	2.37	25.8
Chip vans[6]			.12/mi	.06/mi	305.28	152.64		457.92	0.31	3.4
Maintenance van[7]	38		.28/SH	.02/mi	10.64	0.88		11.52	0.01	0.1
Fuel truck[8]	38	15.2	.55/SH	2.50	20.90	38.00		58.90	0.04	0.4
Dozer[9]	38	7.6	37.85	28.07	287.66	213.33	76.00[12]	576.99	0.40	4.3
Saw log trailer[10] with loader	18							91.80	0.06	0.7
TOTAL					5,578.14	4,284.99	3,435.00	13,389.93	9.20	100.0

[1] SH = scheduled hours.

[2] PH = productive hours.

[3] 1980 U.S. dollars.

[4] Labor cost = $10.00/hr. for each operator including all fringe benefits.

[5] Cost per ton based on 1,455.03 tons of chips produced.

[6] Hauling distance = 24 miles (one way) and 53 van loads.

[7] Fixed cost = $0.28/SH x 38 SH = $10.64. Operating cost = $0.02/mi x 44 mi = $0.88.

[8] Assumed 40-percent utilization.

[9] Assumed 20-percent utilization.

[10] 17 percent of saw log trailer cost allocated to the production of chips. 18 SH X .17 X $30/SH (Contracted cost) = $91.80.

[11] 7 percent of skidding time allocated to the production of saw logs. Saw log tonnage equaled 7 percent of total.

[12] Chain flail operator also operated dozer. Total labor cost of flail and dozer = 38 SH X $10/SH = $380.

Table 10.—*Harvesting and transportation costs for producing chips on site 36B based on productive hours*

Operation	**Time on job**		**Machine rate F**	**O**	**Total fixed cost**	**Total operating cost**	**Total labor cost[4]**	**Total cost**	**Cost per ton[5]**	**Total cost**
	SH[1]	*PH[2]*	*Dollars[3]*							*Percent*
Feller/buncher	33	25.0	32.38	24.18	809.50	604.50	330.00	1,744.00	3.26	33.3
Skidder	21	14.5	27.31	28.70	396.00	416.15	210.00	1,022.15	1.91	19.5
Chipper	12	9.8	30.38	20.60	297.72	201.88	120.00	619.60	1.16	11.8
Chain flail	12	9.8	21.20	13.16	207.76	128.97	108.00[10]	444.73	0.83	8.5
Trucks[6]		—	.37/mi	.39/mi	319.68	336.96	480.00	1,136.54	2.13	21.8
Chip vans[6]		—	.12/mi	.06/mi	103.68	51.84	—	155.52	0.29	3.0
Maintenance van[7]	12	—	.28/SH	.02/mi	3.36	0.88	—	4.24	0.01	0.1
Fuel truck[8]	12	4.8	0.55	2.50	2.64	12.00	—	14.64	0.03	0.3
Dozer[9]	12	1.2	37.85	28.07	45.42	33.68	12.00[10]	91.10	0.17	1.7
TOTAL					2,185.76	1,786.86	1,260.00	5,232.52	9.79	100.0

[1] SH = scheduled hours.

[2] PH = productive hours.

[3] 1980 U.S. dollars.

[4] Labor cost = $10.00/hr for each operator including all fringe benefits.

[5] Cost per ton based on 534.21 tons of chips produced.

[6] Hauling distance = 24 miles (one way) and 18 van loads.

[7] Fixed cost = $0.28/SH x 12 SH = $3.36. Operating cost = $0.02/mi x 44 mi = $.88.

[8] Assumed 40-percent utilization.

[9] Assumed 10-percent utilization.

[10] Chain flail operator also operated dozer. Total labor cost of flail and dozer = 12 SH X $10/SH = $120.

Table 11.—*Harvesting and transportation costs for producing chips on site 36C based on productive hours*

Operation	**Time on job**		**Machine rate F**	**O**	**Total fixed cost**	**Total operating cost**	**Total labor cost[4]**	**Total cost**	**Cost per ton[5]**	**Total cost**
	SH[1]	*PH*[2]				*Dollars*[3]				*Percent*
Feller/buncher	44	35.5	32.38	24.18	1,149.49	858.39	440	2,447.88	2.55	25.9
Skidder	29	24.8	27.31	20.87	677.29	517.58	290	1,484.87	1.55	15.7
Chipper	30	22.8	30.38	20.60	692.66	469.68	300	1,462.34	1.52	15.4
Chain flail	30	24.3	21.20	13.16	515.16	319.79	270[10]	1,104.95	1.15	11.7
Trucks[6]	—	—	.37/mi	.39/mi	586.08	617.76	1,200	2,403.84	2.51	25.4
Chip vans[6]	—	—	.12/mi	.06/mi	190.08	95.04	—	285.12	0.30	3.0
Maintenance van[7]	30	—	.28/SH	.02/mi	8.40	0.96	—	9.36	0.01	0.1
Fuel truck[8]	30	12	.55	2.50	6.60	30.00	-	36.60	0.04	0.4
Dozer[9]	30	3	37.85	28.07	113.55	84.21	30[10]	227.76	0.24	2.4
TOTAL					3,939.31	2,993.41	2,530	9,462.72	9.87	100.0

[1] SH = scheduled hours.
[2] PH = productive hours.
[3] 1980 U.S. dollars.
[4] Labor cost = $10.00/hr. for each operator including all fringe benefits.
[5] Cost per ton based on 958.34 tons of chips produced.
[6] Hauling distance = 24 miles (one way) and 33 van loads.
[7] Fixed cost = $0.28/SH x 30 SH = $8.40. Operating cost = $0.02/mi x 48 mi = $.96.
[8] Assumed 40-percent utilization.
[9] Assumed 10-percent utilization.
[10] Chain flail operator also operated dozer. Total labor cost of flail and dozer = 30 SH X $10/SH = $300.

Table 12.—*Harvesting costs for producing saw logs on site 36A based on productive hours*

Operation	**Time on job**		**Machine rate F**	**O**	**Total fixed cost**	**Total operating cost**	**Total labor cost[4]**	**Total cost**	**Cost per ton[5]**	**Total cost**
	SH[1]	*PH*[2]				*Dollars*[3]				*Percent*
Sawyer (felling, limbing, bucking)	59	44.8	—	—	—	—	590	590.00	32.29	45.9
Skidder[6]	5.5	4.0	27.31	20.87	109.24	83.48	55	247.72	13.56	19.3
Saw log trailer[7] (with loader)	18	7.4	30/SH	—	—	—	—	448.20	24.53	34.8
TOTAL								1,285.92	70.38	100.0

[1] SH = scheduled hours.
[2] PH = productive hours.
[3] 1980 U.S. dollars.
[4] Labor cost = $10.00/hr. for sawyer and skidder operators including all fringe benefits.
[5] Cost per Mbf based on 18.27 Mbf of saw logs produced.
[6] Seven percent of skidding time allocated to the production of saw logs. Saw log tonnage equaled 7 percent of total.
[7] Eighty-three percent of saw log trailer cost allocated to the production of saw logs. 18 SH x .83 x $30/SH (contracted cost) = $448.20.

Table 13.—*Harvesting costs for producing saw logs on site 36B based on productive hours*

Operation	Time on job		Machine rate F	Machine rate O	Total fixed cost	Total operating cost	Total labor cost[4]	Total cost	Cost per ton[5]	Total cost
	SH[1]	*PH*[2]	*Dollars*[3]							*Percent*
Sawyer (felling, limbing, bucking)	32	24.3	—	—	—	—	320	320.00	21.23	45.9
Forwarder	14	11.4	10.86	10.01	123.80	114.11	140	377.91	25.07	54.1
TOTAL								697.91	46.30	100.0

[1] SH = scheduled hours.
[2] PH = productive hours.
[3] 1980 U.S. dollars.
[4] Labor cost = $10.00/hr for sawyer and forwarder operator including all fringe benefits.
[5] Cost per Mbf based on 15.075 Mbf of saw logs produced.

Table 14.—*Harvesting costs for producing saw logs on site 36C based on productive hours*

Operation	Time on job		Machine rate F	Machine rate O	Total fixed cost	Total operating cost	Total labor cost[4]	Total cost	Cost per ton[5]	Total cost
	SH[1]	*PH*[2]	*Dollars*[3]							*Percent*
Sawyer (felling, limbing, bucking)	87	65.5	—	—	—	—	870	870.00	44.19[5]	52.5
Skidder	12	10.0	27.31	20.87	273.10	208.70	120	601.80	45.75[6]	36.3
Forwarder	8	5.1	10.86	10.01	55.39	51.05	80	186.44	28.53[7]	11.2
TOTAL								1,658.24	84.22	100.0

[1] SH = scheduled hours.
[2] PH = productive hours.
[3] 1980 U.S. dollars.
[4] Labor cost = $10.00/hr. for sawyer and equipment operators including all fringe benefits.
[5] Cost per Mbf based on 19.69 Mbf of saw logs produced.
[6] Cost per Mbf based on 13.155 Mbf of saw logs skidded.
[7] Cost per Mbf based on 6.535 Mbf of saw logs forwarded.

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Sturos, John A.; Miyata, Edwin S.; Steinhilb, Helmuth M.; Barron, Robert M.

The economics of a mechanized multiproduct harvesting system for stand conversion of northern hardwoods. Res. Pap. NC-237. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 12 p.

Describes chip and saw log yields, production, costs, and potential profits of clearcutting, down to a 2-inch diameter, a northern hardwood poletimber stand by a conventional whole-tree harvesting system and three sawtimber stands by several combinations of whole-tree chipping and saw log recovery.

KEY WORDS: Integrated harvesting, residue recovery, whole-tree harvesting, saw log sorting.

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Forest Service

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Research Paper **NC-238**

Productivity of a Large-Wheeled Skidder and Roller Chopper for Preparing Sites

Edwin S. Miyata, Helmuth M. Steinhilb, Glenn D. Mroz, and Lynne A. Coyer

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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PRODUCTIVITY OF A LARGE-WHEELED SKIDDER AND ROLLER CHOPPER FOR PREPARING SITES

Edwin S. Miyata, *Research Industrial Engineer,*
Houghton, Michigan, now located at:
Pacific Northwest Forest and Range Experiment Station,
Seattle, Washington,
Helmuth M. Steinhilb, *Research Forester,*
Houghton, Michigan,
Glenn D. Mroz, *Instructor,*
Forestry Department,
Michigan Technological University,
Houghton, Michigan,
and **Lynne A. Coyer,** *Industrial Engineering Technician,*
Houghton, Michigan, now located at:
Rhinelander, Wisconsin

The demand for wood for fiber and energy uses continues to increase. From 1976 to the year 2030, total wood consumption in the United States is expected to increase from 166 million cords (602 million m^3) to 358 million cords (1,298 million m^3) (Vento 1980).

In 1979 Wisconsin was the leading paper-producing State in the Nation with an output of approximately 3.6 million tons or about 12 percent of the United States production (Skinner 1981). To meet its pulp and paper mill requirements, Wisconsin imports about 40 percent of the softwood pulpwood and 86 percent of the softwood residues from other States and Canada (table 1). The shortage of conifers and the escalation of conifer stumpage prices are providing increasing incentive to both public and private landowners in Wisconsin to convert poor quality hardwood stands to conifers.

An essential step in converting these hardwood stands is preparation of the site to reduce the amount and vigor of competing vegetation and to allow adequate survival and growth of the planted conifers (Burns and Hebb 1972, Knighton 1972, and Trevison 1977). Site preparation may include: (1) mechanical methods such as chopping, shredding, root raking, dozing, discing, tilling, etc.; (2) chemical methods using herbicides to kill competing trees and plants; or (3) prescribed burning. To develop economical and biologically feasible site preparation techniques or systems, cost and productivity information must be determined for the machines and the methods presently being used together with descriptions of the sites being treated. But documented data indicating the effectiveness of such machines and systems is generally lacking. In an effort to provide needed documentation, we studied the cost, productivity, and soil compaction of a large-wheeled skidder and roller chopper used to prepare a mixed hardwood site in Wisconsin.

Table 1.—*1979 Wisconsin pulpwood situation*

Raw material	Production	Exports	Imports	Mill receipts	Imports as percentage of mill receipts[1]
	--------------*Rough stand cords*------------ -----				*Percent*
Softwood	506,148	15,381	326,891	817,658	40
Hardwood	1,343,278	26,259	409,076	1,726,095	24
Softwood residue	48,523	2,588	285,920	331,855	86
Hardwood residue	210,723	40,644	21,485	191,564	11
TOTAL	2,108,672	84,872	1,043,372	3,067,172	34

Source: Wisconsin Wood Marketing Bulletin, Wisconsin Department of Natural Resources, Madison, Wisconsin 53711, February 1981.

[1] Calculated by Edwin S. Miyata and Helmuth M. Steinhilb.

TECHNICAL INFORMATION OF EQUIPMENT USED

Equipment used on this project was a Pettibone[1] master 1500 skidder pulling a Fleco Corporation Model SS812 single drum roller chopper (fig. 1).

The Pettibone Master 1500 skidder was equipped with a Carco F-50PS rear, frame-mounted winch with a maximum line pull of 50,000 pounds (22,680 kg) and line speeds from 100 to 400 fpm (30.5 to 121.9 m in). The skidder had a four-speed powershift transmission, four-wheel pivoted power steering, and a Detroit Diesel 6V92 N75 engine developing 255 hp at 2,100 rpm.

The roller chopper drum was 5 feet (1.52 m) in diameter, 8 feet (2.44 m) wide, and was equipped with 12 straight cutting blades—each 3/4 inch (1.9 cm) thick, 10 inches (25.4 cm) deep, and 8 feet (2.44 m) long—equally spaced around the circumference. Weight of the roller chopper and hitch was 14,090 pounds (6,391 kg) empty and 22,420 pounds (10,170 kg) when filled with 1,000 gallons (3,785 l) of water. Detailed specifications of the Pettibone Master 1500 skidder are given in Appendix A. The hitch connecting the roller chopper to the skidder allowed both vertical and horizontal movement of the roller chopper (fig. 2).

The list prices of the skidder and roller chopper were $136,620 and $20,990, respectively, including extra attachments.

FIELD TESTING

In May 1981, personnel from the USDA Forest Service's Forestry Sciences Laboratory, Houghton, Michigan, working in cooperation with Consolidated Papers, Inc., Rhinelander, Wisconsin, and Michigan Technological University, Houghton, Michigan, field tested the skidder and roller chopper. Detailed time studies were conducted to evaluate equipment cost, productivity, and effectiveness for site preparation. The treated area also was analyzed for soil compaction.

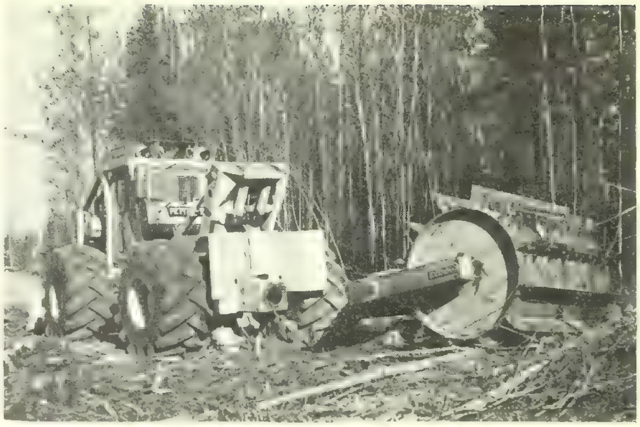

Figure 1.—*Pettibone Master 1500 skidder and Fleco Corporation Model SS812 single drum roller chopper.*

The study area was 5 miles northeast of Rhinelander, Wisconsin. The topography was flat to gently rolling with slopes averaging about 7 percent and maximum slopes not exceeding 25 percent. The soil was a well drained loamy sand. The area roller chopped was 23.4 acres (9.47 ha).

Just prior to site preparation, the light, scattered stand of aspen, red maple, red oak, and white and red pine was logged for pulpwood and a few pine saw logs. The stand remaining after logging contained about 700 trees per acre (1,730 trees per ha) with an average d.b.h. of 2 inches (5.08 cm) and a basal area of 15 square feet per acre (3.44 m²/ha) (fig. 3).

RESULTS

The productive time of the skidder and roller chopper included the elements (1) "chopping"—the forward motion of the skidder and roller chopper; and (2) "back up"—the reverse movement of the machine

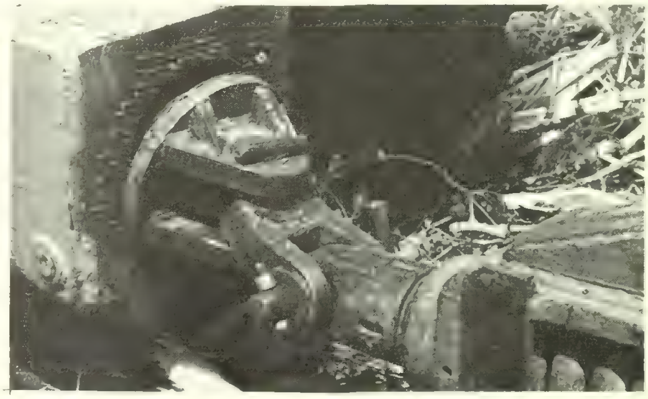

Figure 2.—*Hitch connecting skidder to roller chopper.*

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[1] *The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.*

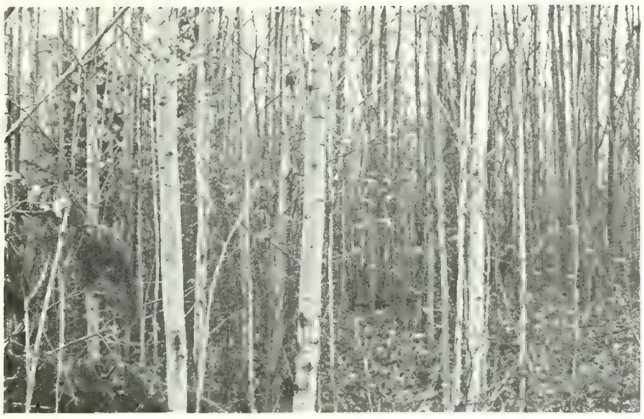

Figure 3.—*Appearance of the study area before roller chopping.*

to maneuver on turns and slopes; and amounted to 12.19 productive hours to treat the 23.4 acres (9.47 ha) as shown below:

Time element	**Hours**	
Chopping	11.54	
Back up	0.65	
Productive time		12.19
Delays	7.28	
Total time		19.47

The delays in roller chopping were classified as either (1) mechanical—caused by malfunction, breakage, or maintenance of the machine; or (2) nonmechanical—those unrelated to mechanical problems or maintenance and are shown below:

	Hours	**Percent**
Mechanical delays		
Overheating	2.26	31
Repair or check	1.13	16
Loose winch	.23	3
Fueling	.25	3
Nonmechanical delays		
Personal (Wait for mechanic, get instructions)	2.23	31
Stuck	.28	4
Clear branches	.09	1
Other (Includes warmup and travel to site	.81	11
TOTAL	7.28	100

Fifty-three percent of the delay time was due to the mechanical category and 47 percent to nonmechanical. The skidder had overheating problems that made it necessary to periodically stop the machine and allow it to cool. Because of the limited time of the study, we did not make a detailed analysis of nonproductive time.

Production rate of site preparation was as follows:

Total area treated	23.4 acres (9.47 ha)
Average width of swath	8 feet (2.44 m)
Total productive time	12.19 hours (PH)
Total scheduled time	19.47 hours (SH)
Productivity (based on PH)	1.92 acres/PH (0.78 ha)
Productivity (based on SH)	1.20 acres/SH (0.49 ha)
Operator time, including travel, maintenance, etc.	25 hours

Estimated machine cost was $61.44 per productive hour for the skidder and $3.63 per productive hour for the roller chopper. Calculated machine rates, method of calculation, and assumptions used for each machine are shown in Appendix B.

Cost per acre for roller chopping is estimated as:

	Total cost	**Cost per acre**
Skidder cost ($61.44/hr x 12.19 PH)	$ 748.95	$32.01
Roller chopper cost ($3.63/hr x 12.19 PH)	44.25	1.89
Operator cost (25 hr x $9.00/hr)	225.00	9.62
TOTAL	$1,018.20	$43.52

Noise levels were measured with a General Radio Noisemeter, Model 1563. Inside the skidder cab with the windows open the noise level was from 90 to 97 decibels with the machine working and 82 decibels when idling. It is recommended the operator wear protective ear plugs.

Overall, the machine was effective in reducing the small trees and slash (fig. 4). The green stems of aspen, balsam, spruce, and red maple up to 4.5 inches (11.4 cm) in diameter were chopped into pieces if the long axis of the stems was oriented parallel to the travel path of the machine (fig. 5A). Any other orientation decreased the effectiveness of chopping (fig. 5B).

SOIL COMPACTION ANALYSIS

Five randomly located soil samples were taken before and after the roller chopping to evaluate onsite surface soil compaction (Blake 1965). Samples

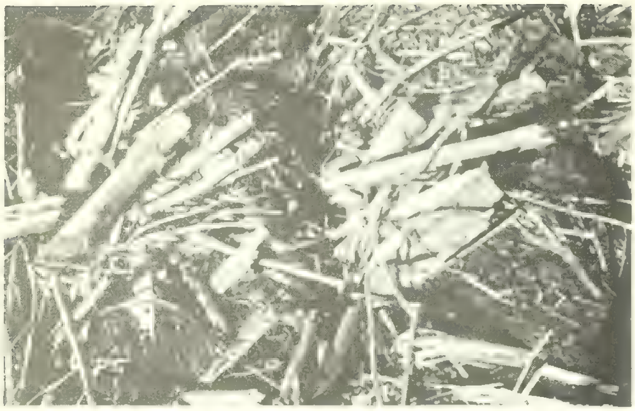

Figure 4.—*Appearance of the study area after roller chopping.*

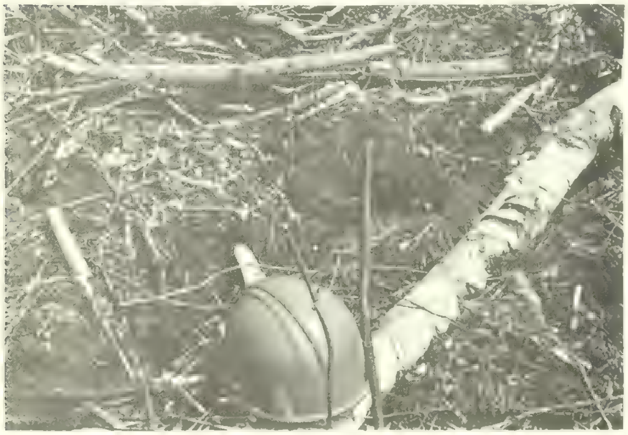

Figure 5A.—*Green stems of trees up to 4.5 inches in diameter were chopped into pieces by the roller chopper when their long axis was oriented parallel to the machine's travel path.*

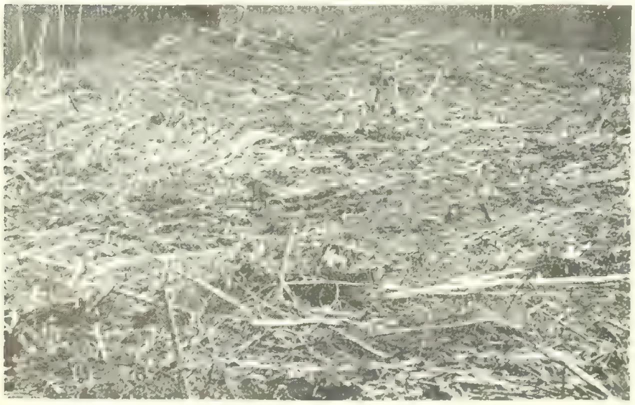

Figure 5B.—*When pieces were not oriented parallel to the machine's travel path, they were not chopped.*

were obtained by digging a hole approximately 7.87 in. (20 cm) in diameter by 11.8 in. (30 cm) deep. Soil bulk density was measured by placing a flexible plastic liner in the hole and pouring water into it to determine the volume of each sample. Soil samples were dried at 221°F (105°C) to a constant weight in the laboratory to determine dry weight and moisture content. Two additional soil samples were taken to determine particle size distribution by the hydrometer method (Day 1965). Soil data were analyzed statistically by a one-way analysis of variance plus covariance using the F-test for significance (Sokal and Rohlf 1969).

The soil on the area was classified as a loamy sand averaging 80 percent sand, 16 percent silt, and 4 percent clay. The average soil moisture content averaged 22 percent. Bulk density values in the surface soil were not found to be significantly lower following roller chopping treatment—they averaged 1.17 g/cc after treatment versus 1.01 g/cc before treatment. However, use of analysis of covariance showed moisture content of the soil to be significant (0.01 level) in describing differences in treatment bulk densities with higher bulk densities being associated with higher moisture content.

This finding suggests that roller chopping on sites with higher soil moisture may cause increased compaction. Future study should be aimed at determining the critical soil moisture level for roller chopping on various textured soils to avoid excessive compaction.

Roller chopping was also observed to bring logging slash into contact with mineral soil. This contact could speed decay and result in accelerated nutrient release from slash, which could be beneficial to regeneration.

DISCUSSION

The average speed of the machine while traveling forward and actually roller chopping was 242 feet per minute (73.76 m/min) with a standard deviation of 46 feet per minute (14.07 m/min). The speed ranged from 166 feet per minute (50.60 m/min) to 353 feet per minute (107.59 m/min). Based on the average traveling speed on this site, we estimated the machine could have chopped an average of 2.67 acres per hour (1.08 ha/hour). However, the actual production was 1.92 acres per hour (0.78 ha/hour) or approximately 72 percent of the estimated production. This is because the machine was not constantly going forward but had to spend some time backing up to make turns or maneuver on slopes. Using the same estimated 72 percent efficiency, the machine *theoretically* could have treated approximately 3 acres per hour (1.21 ha/hour), based on the fastest speed on this site. Higher productivity results in lower machine cost per acre and the costs per acre would be substantially lower at the faster machine speeds:

Productivity Acres per hour	Machine cost per acre excluding labor
1.92 (this study)	$33.90
2.50	$26.03
3.00	$21.69

CONCLUSIONS

1. The Pettibone Master 1500 skidder and Fleco SS812 roller chopper satisfactorily prepared the site for field planting at an acceptable cost per acre and without excessively compacting the soil.
2. The machine actually treated about 2 acres per productive hour. The speed capabilities of the machine suggest that productivity could increase to between 2.5 and 3.5 acres per hour (1.01 to 1.42 ha/hour) with a proportionate reduction in cost per acre or per hectare.
3. This work reports on only one case study. Further study should be done on different sites after roller chopping to determine the effect of the treatment on planting costs, the development of competing vegetation, the need for further plantation release, and plantation survival and growth.

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APPENDIX A
DETAILED SPECIFICATIONS FOR PETTIBONE MASTER 1500 SKIDDER

MANUFACTURER: Pettibone Corporation
FUNCTION: Skidder

FEATURES: 4 speed powershift transmission. 4 wheel drive. 4 metal pivoted power steering.

SPECIFICATIONS: *Power Unit & Train:* Detroil Diesel 6V92 N75 engine. 255 HP @ 2100 rpm. Displacement 522 in^3 (9046 cc). Power shift transmission. 4 speeds. Torque converter. Travel speeds (fwd & rev): 1st 1.6 mph (2.57 kph), 4th 12.2 mph (19.62 kph).

Operating Information: Brakes: service disc type, parking internal expanding. Steering: hydraulic power articulated frame 40° each way. Fuel capacity: 70 gal (265 l). Dimensions: length (less blade) 22′ 2″ (6.76 m), wheel base 10′ 8″ (3.25 m), height 10′ 3″ (3.12 m), width 10′ 3″ (3.12 m), clearance 21″ (53 cm). Oscillation: 11° each side of center.

Winch: Carco F-50PS mounted on rear frame. Cable capacity: 7/8 inch (2.2 cm) x 255 ft (77.7 m). Max line pull: 50,000 lb (22,680 kg). Line speeds: 100 to 400 fpm (30.5 to 121.9 m).

Hydraulics: 2 commercial shearing pumps. 46 gpm (174 lmp) @ 2,100 rpm & 1,500 psi (105.5 kg/cm^2)

Electrical: 12 V system.

Tires: 26.5–25 x 16 PR Loggers Special.

APPENDIX B CALCULATION OF THE HOURLY MACHINE RATES

Roller Chopper Machine Rate

Description

Manufacturer Fleco Model SS812 H.P —

Purchase Cost: $ 20,990.00

Less: Tire Cost - $ ---

Total Initial Investment (P) $20,990.00

Salvage Value (S) (20 % of P)

Estimated Life (n) 10 years

Working Days/Year 250 days

Scheduled Hours/Year (SH) 2,000 SH

Utilization (U) 70 %

Productive Hours/Year (PHG) 1,400 PH

Average Value of Investment (AVI) = $\frac{(P - S)\ (n + 1)}{2n} + S$ $13,433.60/yr

II. Fixed Cost
Depreciation (D) $\frac{P - S}{n}$ $ 1,679.20/yr

Interest 18 %
Insurance 3 %
Taxes 3 %

Total 24 % X (AVI = $ 13,433.60 /yr) $ 3,224.06/yr
Total fixed cost per year $ 4,903.26/yr
fixed cost per SH $ 2.45/SH
fixed cost per PH (A)* $ 3.50/PH

III. Operating Cost
Maintenance and Repair (10 % of $\frac{(P - S)}{n \times PH}$ $ 0.12/PH

Fuel Cost $ --- /PH
Oil and Lubricants $ 0.01/PH
Tires + $\frac{1.15 \times \text{tire price}}{\text{Total tire life in hours (miles)}}$ $ --- /PH

TOTAL OPERATING COST PER PH (B)* $ 0.13/PH

*Machine Rate per PH (A + B) $ 3.63/PH

Large-Wheeled Skidder Machine Rate

Description

Manufacturer Pettibone Model Master 1500 H.P 255

Purchase Cost: $ 136,620.00

Less: Tire Cost - $ 6,400 @ $1,600 ea.

Total Initial Investment (P) $130,220.00

Salvage Value (S) (20 % of P)

Estimated Life (n) 5 years

Working Days/Year 250 days

Scheduled Hours/Year (SH) 2,000 SH

Utilization (U) 67 %

Productive Hours/Year (PHG) 1,340 PH

Average Value of Investment (AVI) = $\frac{(P - S)(n + 1)}{2n}$ + S $88,549.60/yr

II. Fixed Cost

Depreciation (D) $\frac{P - S}{n}$ $20,835.20/yr

Interest 18 %
Insurance 3 %
Taxes 3 %

Total 24 % X (AVI = $ 88,549.60 /yr) $21,251.90/yr
Total fixed cost per year $42,087.10/yr
fixed cost per SH $ 21.04/SH
fixed cost per PH (A)* $ 31.41/PH

III. Operating Cost

Maintenance and Repair (50 % of $\frac{(P - S)}{n \times PH}$ $ 7.77/PH

Fuel Cost = 0.037 X HP X 1.50/gal $ 14.15/PH
Oil and Lubricants (40% of fuel cost) $ 5.66/PH
Tires + $\frac{1.15 \times \text{tire price}}{\text{Total tire life in hours (miles)(3,000)}}$ $ 2.45/PH

TOTAL OPERATING COST PER PH (B)* $ 30.03/PH

*Machine Rate per PH (A + B) $ 61.44/PH

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Miyata, Edwin S.; Steinhilb, Helmuth M.; Mroz, Glenn D.; Coyer, Lynne A.

Productivity of a large-wheeled skidder and roller chopper for preparing sites. Res. Pap. 238. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 8p.

Discusses the results of a field test of a Pettibone Master 1500 skidder and Fleco Corporation SS812 roller chopper for site preparation work in Wisconsin. Includes cost, productivity, and effectiveness of site preparation on 23.4 acres (9.47 ha).

KEY WORDS: Species conversion, hardwoods, conifers, costs, production, effectiveness.

United States Department of Agriculture

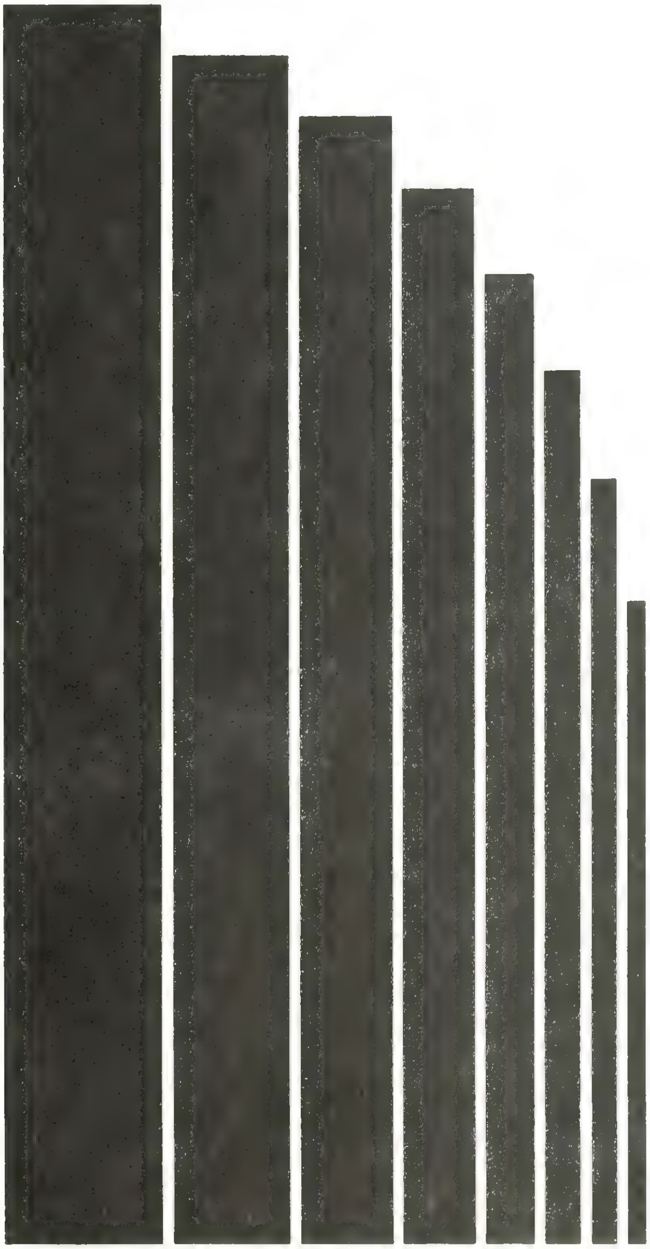
Forest Service

North Central Forest Experiment Station

Research Paper **NC-239**

Height Growth to Age 8 of Larch Species and Hybrids in Wisconsin

Don E. Reimenschneider and Hans Nienstaedt



Riemenschneider, Don E.; Nienstaedt, Hans.
Height growth to age 8 of larch species and hybrids in Wisconsin. Res. Pap. NC-239. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 6 p.

Height growth of tamarack; Siberian, European and Japanese larch; and hybrids between the European and Japanese larch were compared in an 8-year-old test in north-central Wisconsin. Hybrids were tallest and the best reached 469 cm (15.4 feet) in mean height at age 8 years from seed. Hybrids exceeded European larch mean height by 12 percent and tamarack by 23 percent. Breeding strategies are discussed.

KEY WORDS: Progeny tests, provenances, breeding strategies, adaptation.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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1983

HEIGHT GROWTH TO AGE 8 OF LARCH SPECIES AND HYBRIDS IN WISCONSIN

Don E. Riemenschneider, *Plant Geneticist,*
and **Hans Nienstaedt,** *Chief Plant Geneticist,*
Rhinelander, Wisconsin

European larch (*Larix decidua* Mill) and Japanese larch (*Larix leptolepis* [Sieb and Zucc] Gard.) have been tested on a limited scale in the North-central States and have demonstrated exceptional early growth. This good performance has stimulated an increasing interest in their management as a fiber crop using shortened rotations and intensive cultural practices (Jeffers and Isebrands 1974). Anticipating this development, we began a test of some of the best materials we could obtain from cooperators in Europe, Canada, and the United States in 1973. Hybrids between the two species as well as the native tamarack (*Larix laricina* (Du Roi) K. Koch) were included. This paper discusses height growth of the collections through 8 years of growth from seed.

PERFORMANCE IN OLDER TEST IN THE UNITED STATES

The good growth has occurred over a wide region. In Michigan, for example, heights of more than 7 m (24 feet) were reached at age 11 for one good European larch seed source from Schlitz, Germany (Barnes 1970). In northern Wisconsin 14 selected trees representing 5 provenances at 25 years from seed averaged 15 m (53 feet) in height and 20 cm (8 inches) d.b.h. (Jeffers and Isebrands 1974). On a more productive site in southwestern Wisconsin a 19-year-old plantation of European larch outperformed two native conifers (table 1), and at 12 years European larch was taller than any other species planted in western Iowa plots (Erdmann 1966). In Maine 27-year-old European larch grew an average of 62 cm (2.04 feet) per year compared to 43 cm (1.40 feet) for white pine (age 30) and 43 cm (1.40 feet) for white spruce (age 27) (Young 1957).

Japanese larch has also performed well. In Michigan, the best seed source produced 7 m trees 10 years after planting and large differences were noted among provenances (Lee 1976). On an adverse site in New York (Cook and Smith 1964) it was the one species that exceeded 9 m (30 feet) 21 years after planting. In Minnesota, at 24 years of age it had grown faster than any of the native conifers of similar ages in adjacent plots (Schantz-Hansen and Hall 1952), but at 45 years of age it had been surpassed by tamarack; red, jack, and white pine; and white spruce (Alm *et al.* 1972).

The hybrid between the two species is generally superior to the parent species. This has been the experience in many tests in Europe. In a typical example the hybrid produced 186 percent (239 m^3 per ha (3,416 cubic feet per acre)) and 168 percent (123 m^3 per ha[1] (1,758 cubic feet per acre)) of the volume produced by the Japanese (135 m^3 per ha (1,929 cubic feet per acre)) and European (73 m^3 per ha[1] (1,089 cubic feet per acre)) standards, respectively (Keiding 1980).

One 25-year-old study in New York compared "Dunkeld" larch with plots of European and Japanese larch. The best hybrid plot produced 162 percent of the volume in the best European larch plot and 110 percent of the volume in the best Japanese larch plot. The hybrid is resistant to larch canker (*Lachnellula willkommii)—a* serious pest on larch in Europe that recently has been reported on tamarack in New Brunswick, Nova Scotia, and Maine (Magasi and Pond 1982, Miller-Weeks n.d.) and on European larch in New England (Hepting 1971). It is resistant to needlecast disease *Mycosphaerella* sp. that has damaged some provenances of European larch in Iowa

---

[1] *These low volumes per hectare were the result of unusually heavy thinning.*

Table 1.—*Comparison of growth among European larch, white pine, and red pine on a productive site in southwestern Wisconsin*[1]

Growth measurement	European larch	White pine	Red pine
D.b.h. (cm)	17 (6.7 in.)	16 (6.3 in.)	15 (5.8 in.)
Height (m)	16.5 (54 ft)	12.0 (39 ft)	10.7 (35 ft)
Basal area (m^2/ha)	29.6 (129 ft^2/A)	29.8 (130 ft^2/A)	34.0 (148 ft^2/A)
Volume (m^3/ha)	189 (2,700 ft^3/A)	143 (2,050 ft^3/A)	147 (2,100 ft^3/A)

[1] Data compiled by Rod Jacobs, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

and southern Wisconsin, and it is not damaged by woolly aphids (*Adelges strobilobius*) (Shafer 1981). The hybrid survives better than the parent species on dry sites (Keiding 1980, Reck 1977).

MATERIALS AND METHODS

We included 37 seedlots in the test. Five seedlots of European larch were open-pollinated collections from selected trees in a 25-year-old stand of European larch at the Argonne Experimental Forest, Hiles, Wisconsin. One collection was made from a Siberian larch in the same stand and probably contained seed of European-Siberian hybrid origin. Four additional lots of European larch were obtained—one each from orchards in Denmark, Germany, Poland, and Canada.

Of the four Japanese larch seedlots, one was from a natural stand collection from Honshu, Japan; one from a Hokkaido, Japan, source received through Denmark; one was from an orchard in East Germany; and one was from a seed orchard of selected trees in Hokkaido, Japan.

Seedlots of *Larix eurolepis* (European x Japanese) were obtained from orchards in Denmark. Two of these hybrid lots involved crosses between selected clones of European larch of Alps origin (females) and selected Japanese larch clones (males). A third hybrid seedlot originated from an orchard consisting of a single selected European clone from Zagnansk, Poland, and several selected Japanese clones. One seedlot of the reciprocal cross (Japanese x European) was obtained from a clonal orchard in Sweden containing one clone of Japanese larch and 10 selected clones of European larch. The origin of the European clones were unknown but probably Scottish.

In addition of known hybrid seedlots, 13 seedlots were obtained from multi-clonal orchards in Scotland and Denmark containing a mixture of European and Japanese clones. Five lots from Scotland were open-pollinated collections from Japanese larch clones and were probably a mixture of Japanese x Japanese and Japanese x European. Three lots from Scotland and five lots from Denmark were open-pollinated collections from European larch and were a mixture of European x European and European x Japanese. The Danish orchard is made up of clones of selected inbreds of the two species. Two additional seedlots of European larch x mixture of European and Japanese larch were obtained from East Germany.

Four open-pollinated single tree collections of tamarack (*Larix laricina*) from Ontario were also included in the study.

Seed was sown in April 1973. Seedlings were grown in plastic tubes in a 1:3:1 sand, peat, perlite growing media in the greenhouse until June. A 20-hour photoperiod and constant 72°F temperature was maintained throughout this phase. Seedlings were transferred to a shadehouse on June 11 and grown under a 20-hour photoperiod and normal outdoor temperatures. The seedlings were transplanted to the Hugo Sauer Nursery at Rhinelander, Wisconsin, in a randomized complete block design in August 1973.

In April 1976 the seedlings were field planted on a sandy loam site at the Harshaw Experimental area, Oneida County, Wisconsin. The previous summer the site was prepared by plowing, disking, and strip-treating with herbicide. The experimental design was randomized complete blocks with 10 replications and 4-tree plots. Because the 3-year-old seedlings were very large (60-150 cm (2 feet–5 feet) tall) and much of their root systems were lost during lifting, most of them were pruned shortly after planting. We removed all of the 1975 terminal shoots from the large seedlings and up to 1-1/2 of the 1975 terminal shoots from the smaller seedlings. Some of the lateral shoots were also removed from the largest seedlings. In the spring of 1977, dead trees were replaced where stock was available.

All trees were measured for total height in 1977 after five growing seasons and again in the fall of 1980 after the trees were 8-years-old from seed. The two height measurements and the 5-year to 8-year increment were analyzed via analysis of variance. Differences between species and hybrids were tested using single degree of freedom comparisons, and the three groups of seedlots from multiclonal orchards (13 lots total) were compared in a separate test.

RESULTS

Mean height for all trees in the test was 410.8 cm (13.5 feet) in the fall of 1980. This represented a mean yearly height growth of more than 51 cm (1.7 feet) from seed. The 5-year to 8-year increment was 218.9 cm (7.2 feet)—much more than half of the total, for a mean yearly growth of almost 73 cm (2.4 feet) for the 3-year-period (table 2). Differences between seedlots were significant for both height measurements and the 5-year to 8-year increment (table 3). Likewise, the mean performance of the hybrids was consistently greater than that of the parent species (table 2, fig. 1).

After 5 years of growth, no differences were found between European larch (mean height 184.9 cm (6.1 feet)) and Japanese larch (mean height 184.8 cm (6.1 feet). During the next 3 years, however, the European larch grew an average of 234.1 cm (7.7 feet) while the Japanese larch grew an average of only 185.3 cm (6.1 feet). Japanese larch had the poorest 5-year to 8-year increment of any group in the test. After 8 years the Japanese larch was only 88 percent as tall as the European larch, and ranked last (table 2, fig. 1).

At 5 years the hybrids ranked 1 and 2 in total height at 216.5 cm (7.1 feet) for European x Japanese and 209.1 cm (6.9 feet) for Japanese x European (table 2). After 8 years, the ranking remained the same. European x Japanese seedlots averaged 469.4 cm (15.4 feet) in total height or 114 percent of the plantation mean while Japanese x European hybrids averaged 448.4 cm (14.7 feet) or 109 percent of the

Table 2.—*Mean heights at 5 and 8 years and 5-year to 8-year height increment of larch seedlots grouped by parentage*

Group	Seedlots	5-year height		Rank	5-year to 8-year increment		Rank	8-year height		Rank
	No.	cm	ft		cm	ft		cm	ft	
Siberian larch	1	182.9	(6.0)	8	248.0	(8.1)	2	430.9	(14.1)	3
European larch	9	184.9	(6.1)	6	234.1	(7.7)	4	419.0	(13.7)	4
Japanese larch	4	184.8	(6.1)	7	185.3	(6.1)	8	370.1	(12.1)	8
European x Japanese	3	216.5	(7.1)	1	252.9	(8.3)	1	469.4	(15.4)	1
Japanese x European	1	209.1	(6.9)	2	239.3	(7.9)	3	448.4	(14.7)	2
Japanese x mixture of Japanese and European	5	190.1	(6.2)	5	203.6	(6.7)	6	393.6	(12.9)	6
European x mixture of Japanese and European	10	193.1	(6.3)	3	224.0	(7.3)	5	417.2	(13.7)	5
Tamarack	4	193.1	(6.3)	3	187.2	(6.1)	7	380.3	(12.5)	7

Table 3.—*Analyses of variance of 5-year and 8-year height and 5-year to 8-year increment of larch seedlots*

Source	df	5-year height MS	5-year height F	5-8 year increment MS	5-8 year increment F	8-year height MS	8-year height F
Reps	9	3,720	4.32**[3]	2,822	3.32**	12,205	4.48*
Seedlots	36	4,238	4.92**	8,576	10.08**	20,621	7.58*
Parent groups	7	4,104	4.77**	23,955	28.15**	35,664	13.10*
Hybrids vs parent species	1	27,128	31.51**	28,297	33.25**	110,838	40.72*
European vs Japanese	1	0	0NS[5]	65,947	77.49**	66,218	24.33*
E x J vs J x E	1	411	.48NS	1,387	1.63NS	3,307	1.21N
JM[1] vs EM[2]	1	320	.37NS	13,872	16.30**	13,333	4.81*[4]
Error	324	861		851		2,772	

[1] JM = Japanese larch x a mixture of Japanese and European larch.

[2] EM = European larch x a mixture of Japanese and European larch.

[3] ** = signififcant at P > 0.99.

[4] * = significant at 0.99 > P > 0.95.

[5] NS = not significant.

plantation mean. No statistically significant differences were found in total height or increment between the two hybrid groups.

The Siberian larch had the lowest 5-year height of all groups in the test (182.9 cm (6.0 feet)). However, between 5 and 8 years of age, this seedlot grew 248.0 cm (8.1 feet) ranking second only to the European x Japanese larch hybrid (252.9 cm (8.3 feet)). At 8 years of age, the Siberian larch was 430.9 cm (14.1 feet) tall and ranked behind both hybrids. Increasingly good performance may indicate a substantial percentage of natural Siberian x European larch hybrids in the seedlot.

Height of seedlots derived from multiclonal orchards was not as great as that of the all-hybrid groups and tended, at all ages, to be intermediate between the parents and the hybrids. By age 8 the two multiclonal groups ranked 5th and 6th, above only Japanese larch and tamarack (table 2, fig. 1). However, the 10 seedlots of the European x mixture of Japanese and European clones (417.2 cm (13.7 feet) height at age 8) gave different results depending on origin. The five Danish lots were the poorest (389.0 cm (12.8 feet) at age 8), and the Scottish sources were second poorest (436.6 cm (14.3 feet)). The two lots from East Germany averaged 458.5 cm (15.0 feet) and were similar to all-hybrid collections. The differences among the three groups were highly significant (F = 9.99).

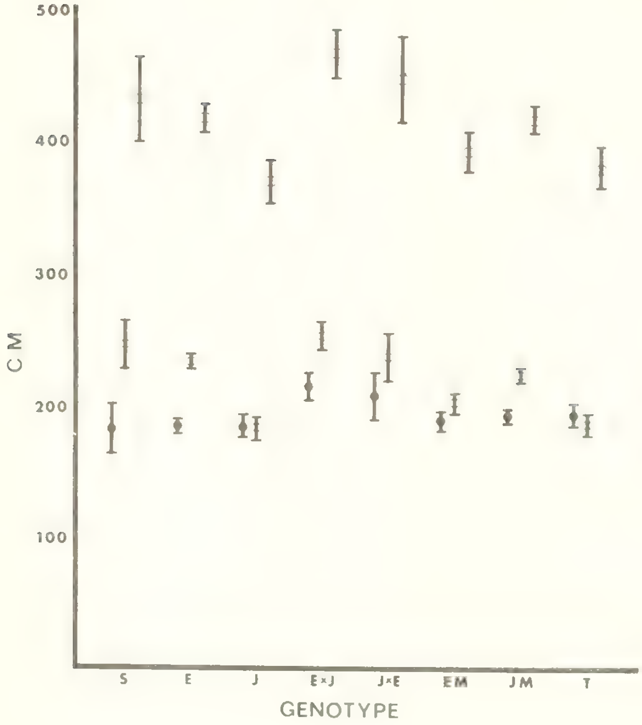

Figure 1.—*Mean height at 5 years (●), 8 years (□), and the 5- to 8-year increment (○) for Siberian (S), European (E), Japanese (J), European x Japanese (E x J), Japanese x European (J x E), European x a mixture of Japanese and European (EM), Japanese x a mixture of Japanese and European (JM) larches and tamarack (T). Confidence intervals are 2 times the standard error of the mean.*

DISCUSSION

The results substantiate the often reported superiority of the first generation hybrid between European and Japanese larch. The magnitude of the superiority over European larch—469.4 cm (15.4 feet) vs. 419.0 cm (13.7 feet) or 12 percent—is low compared to other experiments, which have reported up to 49 percent superiority. At age 8 in our study the hybrid was 23 percent taller than tamarack on the average.

Pure European larch also performed well; on average, the populations exceeded tamarack by 10 percent. The two best sources were from single tree collections made in a provenance test growing near Rhinelander. One represented a provenance mix from the Austrian Alps (600-1,200 m (2,000 feet–4,000 feet)) the other a mix of low elevation German collections of which several were from plantations. The best provenance collection was from Blizyn, Poland. These three collections were from 19 to 22 percent taller than tamarack collections.

The poor performance of Japanese larch in this study is not unique. Farnsworth *et al.* (1972) mentioned an example in which "heavy (spring) frosts in successive years were partially responsible for the rapid decline of two Michigan plantations located in frost pockets". They also mentioned dieback from winter cold in the nursery. With one exception the trees became hardier as they grew older. But in a Wisconsin test of 22 provenances, some seed sources showed heavy damage and others light damage several years after planting. The severity of spring as well as winter damage was correlated with differences among mountains of origin.

The best seed source in our test was from a seed orchard on Hokkaido—the northernmost Japanese island. Natural populations of larch occur on the Japanese island of Honshu, between approximately 35° and 37°N. Hokkaido is located between approximately 42° to 45°N; day-length there is closer to that in Wisconsin and, with the exception of the coastal regions, the climate is colder than it is within the native range. Farnsworth *et al.* (1972) reported significant variation in the degree of damage from both spring frosts and winter cold. The results suggests that selection in Hokkaido plantations in a colder environment has resulted in a population pre-adapted to the cold Wisconsin environment as well. Considering the variation observed in the North Central States (Farnsworth *et al.* 1972), our results with the Hokkaido selection suggest that breeding of the best trees from the best adapted provenances may yield better adapted trees. The better performance of the multi-clonal seedlots developed in the more continental climate in East Germany may point in the same direction.

Tree breeders have several options for breeding *Larix* in the north-central region. Together with previously published information our results substantiate that volume production can be improved in a single generation by hybridizing European and Japanese larch. Another gain from hybridizing is the introduction of pest resistance mentioned earlier.

A multigeneration hybrid breeding program is a more complex proposition. Two avenues are available to improvement: (1) developing a new population (equivalent to a new species or race) using hybrids as the breeding stock; (2) breeding the individual parent species using a recurrent selection scheme. The hybrids would be produced from the improved products of breeding of the two species.

With our current knowledge of *Larix* genetics, particularly as it relates to the adaptation to the harsh environment in the north-central region, and with the *Larix* materials now available, it is not possible to determine which option will be most effective. Lester (1975) has discussed the problems that may complicate advanced breeding of hybrids as considered under option 1. He listed the following factors as those that could restrict access to desired gene combinations: nonrandom assortment of genes at meiosis, pleiotropy, nonrandom elimination of gametes or genotypes, sterility in the F_1 hybrids, and hybrid breakdown in the F_2. Available information on the performance of the parent species and F_1 hybrids is not sufficient to determine the impact of these factors. However, we have observed no sterility problems in the F_1.

Hyun (1974) has described the performance of a hybrid F_2 pine of a combination in which one parent species was not climatically adapted. Under more severe conditions, the F_2 did not perform as well as the F_1. He suggested that in the F_2 generation individuals segregating in the direction of the nonadapted parent suffer cold damage.

Our results show on the one hand that our Japanese larch collections are poorly adapted to the test site, and on the other hand that hybrid superiority is low compared to results elsewhere. The hybrids were developed in western Europe in milder climates; perhaps the hybrids would have performed better if the Japanese larch parents had been selected in our continental climate. If this assumption is correct, the available hybrids do not represent the best parent breeding stock. Option 2 will then become an important first step. Recurrent selection for improved growth in both parent species would provide breeding material for producing improved pure species stock and improved hybrids. The initial choice of within-species improvement would not preclude later breeding within hybrid populations. At any generation the breeder should have the flexibility to pursue either intra-specific or inter-specific breeding. Because additional research is needed before the efficiency of alternative breeding systems can be determined, it will be very important to maintain as many breeding options as possible.

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United States Department of Agriculture

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North Central Forest Experiment Station

Research Paper **NC-240**

Homogeneous Macroclimatic Zones of the Lake States

H. Michael Rauscher

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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June 1984

HOMOGENEOUS MACROCLIMATIC ZONES OF THE LAKE STATES

H. Michael Rauscher, *Research Forester,*
Grand Rapids, Minnesota

The prevailing weather conditions of a region, its climate, influences the development of the soil and the vegetation in that region. Many attempts have been made to classify climates in order to explain the distribution of forests and other vegetation types (Spurr and Barnes 1980). Each classification has shown some interesting delineations, but none has been completely satisfactory (Daniel *et al.* 1979, Spurr and Barnes 1980).

Another reason to classify climate is to decompose the abundant natural variations of forest ecosystems. The process of classifying climate produces homologous units having characteristic features of their own and requiring distinct treatment (Zon 1908, Miller and Auclair 1974). These homogeneous climatic classes, called homoclimes, help us organize our knowledge, bring out and understand relations among the homoclimes, and establish classes useful for practical, applied purposes. Identification of homoclimes reduces within-class variation to help in predicting future behavior, in estimating productivity, and in extending and extrapolating research results.

Homoclimes can be used to statistically remove the effect of macroclimate from the dependent variables in experimental research data. Yield tables should be prepared by homologous units, based within known homoclimes, and these same units should be the basic units of experimental forestry work (Zon 1908). Homoclimatic zones may serve as a comprehensive frame of reference for more specific sets of observations such as intensive, site-specific studies (Miller and Auclair 1974). Homoclimes are likely to identify regions where tree growth, regeneration, stand structure, and composition are similar (Miller and Auclair 1974). Wilde (1976) stresses that the relations between productive capacity of soils and the growth of forest stands undergo significant, even radical, modifications in going from one climatic region to another. Broad, climate-negligent generalizations should be regarded with extreme suspicion. Loucks (1962) warns that bio-environmental investigations and relations should be restricted to "small regions of essentially uniform climate". Extrapolation of such relations outside the climatic zone of the study can seldom be justified (Loucks 1962).

Homoclimes have not been defined for the Lake States—Michigan, Minnesota, and Wisconsin. In Canada, homoclimes have been defined for the Maritime Provinces (Putnam 1940), insular Newfoundland (Nicholson and Bryant 1972), northern Ontario (Chapman 1953), and southern Ontario (Putnam and Chapman 1938). Climatic descriptions in the eastern United States have been either too broad to be of much utility (Kendall 1935) or have failed to synthesize the important climatic variables into homoclimatic zones (Borchert 1950, Lull 1968, Nelson and Zillgitt 1969, Merz 1978).

This paper describes and summarizes the macroclimate of the Lake States by defining and mapping homoclimatic zones.

METHODS

The various elements of climate affect forest vegetation through the three most essential conditions of plant life: heat, light, and moisture (Putnam and Chapman 1938, Zon 1941). I selected variables estimating these three influences from generally available meteorological records (Appendix A). Several considerations were used to select variables. Summary data for the months of January, April, July, and October were used to estimate seasonal variation. The variables selected had to be available for all three States. Finally, the variables chosen had to express the maximum amount of variation across the region so as to increase the information content of the data base. For example, mean monthly possible sunshine in January was selected as a cloudiness index because neither July nor the annual mean monthly figures showed much regional variation.

A data base was compiled for Michigan, Wisconsin, and Minnesota using readings from the National Oceanic and Atmospheric Administration (NOAA) network of climatological data stations and published isopleth diagrams (isograms) (fig. 1, table 1). Whenever possible, published isogram maps were used to extract the value of each variable at each grid location. Where published isograms were not available, data for the latest available 30-year normals were used to generate isograms. Unattenuated potential solar radiation values were computed using program RAD (Hill 1976).

A systematic grid system with cells measuring 15 by 15 miles was superimposed on a county level map of the Lake States (USDA 1952). Data from published isograms or isograms constructed from NOAA summary reports were related to this grid system and identified by reference to the nearest grid coordinate.

The resultant data base had 846 observations, each corresponding to a grid intersection, and 53 primary variables. Thirty of the 53 variables were temperature related, 14 were precipitation related, and 9 were radiation related. A principal components analysis was executed for the 30 temperature related variables, the 14 precipitation related variables, and the 9 radiation related variables separately using the FACTOR procedure in SAS79 (Helwig and Council 1979). This analysis yielded two temperature components, accounting for 86 percent of the variation; three precipitation components, accounting for 81 percent of the variation; and two radiation components, accounting for 91 percent of the variation. (A detailed description and a worked example of principal component analysis are given in Appendix D.)

Table 1.—*Summary of the locations of the NOAA recording Stations in the Lake States*

State	Urban	Rural[1]	Airports
Michigan	319	47	11
Minnesota	118	2	3
Wisconsin	240	15	2
Total	677	64	16

[1] More than 3 miles from a post office.

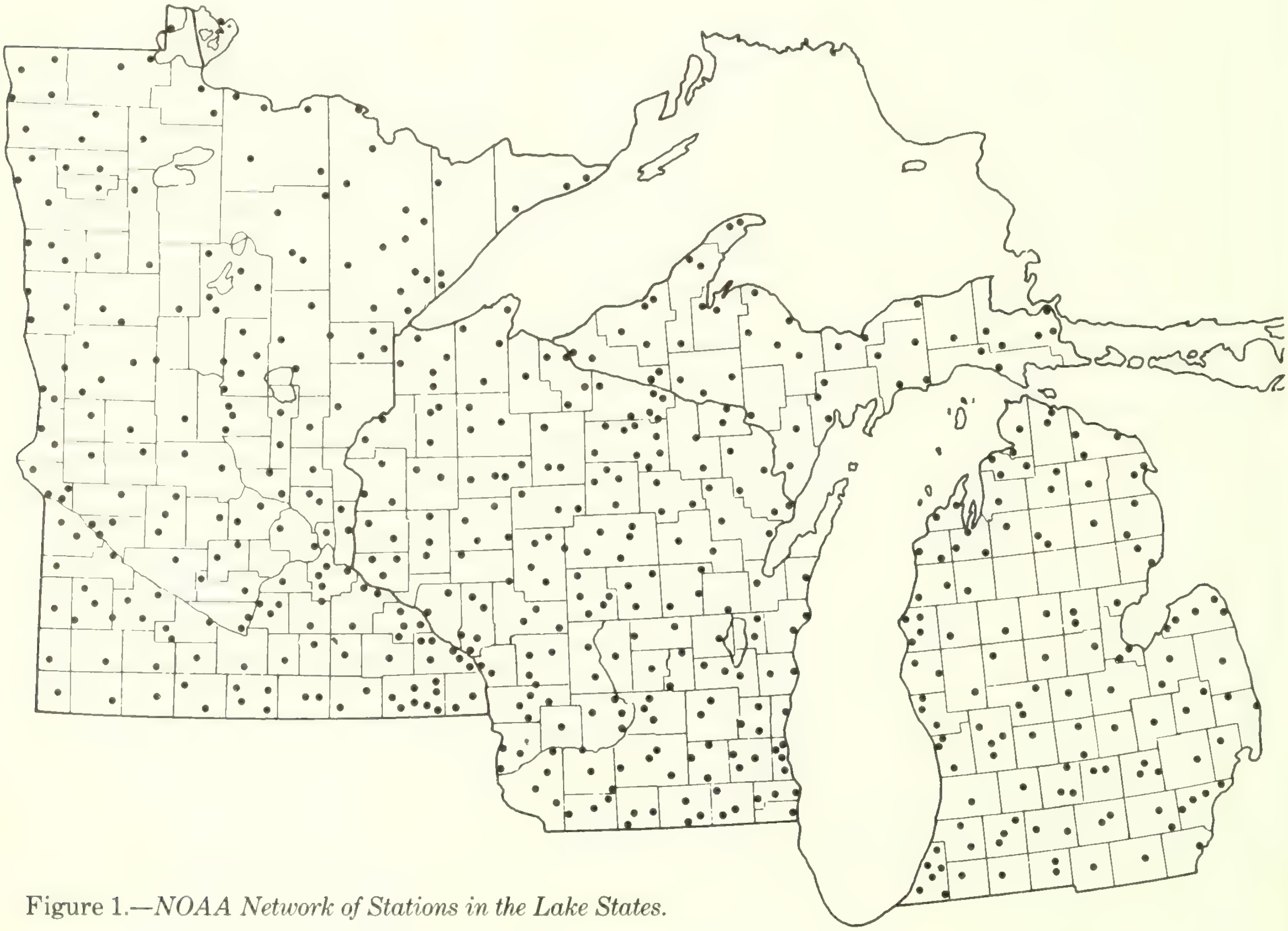

Figure 1.—*NOAA Network of Stations in the Lake States.*

This new data set, consisting of 846 observations and 7 components, was subjected to the SAS79 procedure FASTCLUS (SAS 1981). FASTCLUS is designed for clustering of large data sets—i.e., more than about 200 observations. Several different clustering algorithms should be employed on the same data set to reveal various facets of the structure (Anderberg 1973). This was not possible because FASTCLUS was the only available computer pro ram that could cluster 846 observations at an affordable cost.

The objective of cluster analysis is to discover a category structure that fits the observational units when little or no a-priori knowledge is available about the structure (Anderberg 1973). The results of cluster analysis may be treated as summary statistics of a *descriptive* nature, much like the mean and variance (Anderberg 1973). The clusters describe which observations seem to be associated and which seem to be foreign to each other. Cluster analysis is not involved with hypothesis testing.

The choice of the number of clusters to select is difficult (Anderberg 1973). After a series of trials, I judged that 20 clusters produced a reasonable set of homoclimes. It must be stressed that although these 20 homoclimes are not unique, I feel reasonably comfortable that the data set supports 20 plus or minus 3 to 4 clusters. When the 846 observations were mapped, only 7 intruded in a homoclime not their own. This is a powerful corroboration of the essential trustworthiness of the 20 final clusters given the data used. When more than 20 clusters were computed, numerous very small clusters resulted and the majority of the large clusters were unchanged. The accuracy of the data set did not seem to support maintaining numerous clusters of small areal extent. Their small size would limit their utility and the danger of spurious clusters seemed too high. Conversely, computing less than 20 clusters did not take full advantage of the refinement of which the data set was capable.

A printout of the raw data set, 846 observations by 53 variables, is available from the author upon request.

RESULTS

Interpreting the Principal Components

An analysis of the factor pattern matrices yields the following interpretation of the meaning of each component (table 2). The components are labeled as follows: LS for Lake States; T,P, or R for temperature, precipitation, or radiation; and a number that indicates the percentage of the total variation accounted for by that component.

The variables with high positive factor loadings (see Appendix D for explanation) in component LST79 are indicated by a "+" and those with high negative loadings are indicated by a "-". The component LST79 will have a large score (see Appendix D for explanation) if the variables with a high positive factor loading are large in magnitude and if the variables with high negative loadings are small in magnitude. Therefore, LST79 is the high/low temperature component because large values in the positive loading group of variables and small values in the negative loading group of variables correspond to a high factor score, which corresponds to hot climatic conditions.

A high factor score on component LST07 represents extreme temperatures—hot summers and cold winters. A low factor score represents the reverse—cool summers and warm winters. This factor represents only 7 percent of the total variation due to temperature. The high negative factor loading on average minimum and average January temperature results from the raw data values being negative. Therefore, large negative values in the raw data, corresponding to cold conditions, translate into a large positive contribution to the component because the double negatives cancel out each other.

Large values of component LSP48 characterize a wet winter and fall with an abundance of snow while low values represent the reverse. Large values of the second precipitation component, (LSP21, signify heavy snowfall in early and late winter. Although total precipitation in April is average or low, it is all snow. Low values signify the reverse, that is, low snowfall amounts concentrated in the middle of the winter. High values of the last precipitation component, LSP12, characterize a zone with high annual precipitation that comes predominantly in the summer.

High values of component LSR63 signify zones with high solar radiation and high evaporation; low values signify the reverse. Finally, high values of component LSR29 signify zones with many clear days throughout the year; low values characterize zones with abundant cloudiness.

Interpretation of the Homoclimes

Figure 2 presents the homoclimatic regions of the Lake States, numbered 1 through 20. To relate each of the 20 homoclimes to the 7 components, a profile plot was prepared (table 3). A profile plot is a graphic aid useful for displaying the relative position of objects across some scale of measure. For example, in table 3 homoclimes are plotted in relation to their median scores on the seven principal components. It is evident that homoclimes 13, 10, 5 and 20 represent the cold temperature extreme and homoclimes 17, 1, 16, and 19 represent the warm temperature extreme (LST79).

Homoclime 10 is singled out by LST07 as having a hot summer and a cold winter—a high temperature extreme between the seasons. Homoclimes 11, 12, 6, and 2 in particular, as well as 7, 1, 19, 16, 17, and 20 show up as having the least extremes between the seasons. For example, in homoclime 10 the difference between the average maximum temperature in July and the average minimum temperature in January is 87°F while in homoclime 11 this difference is only 68°F (Appendix B). (Appendix B contains a list of the median value by homoclime, in raw data units, of each variable used in the analysis.)

The relation of homoclimes on LSP48 identifies homoclime 12 as having a snowy fall and winter while homoclimes 10, 3, 8, 9, and 15 get little snow. The average total snowfall in January in homoclime 12 is 35 inches while in homoclime 10 it is 8 inches. Homoclimes 12 and 20 receive large amounts of snow in early and late winter (LSP21) while homoclimes 19, 16, 1, and 17 get their snowfall primarily in midwinter. Homoclime 18 experiences high amounts of annual precipitation, most of which comes in the

Table 2.—*The factor pattern matrix from the principal components analysis for the Lake States*

TEMPERATURES

Variable	Variable codes[1]	Factor code	
		LST79[2]	LST07[2]
Avg. temp. Jan.	T1	0.9 +[3]	-0.3 -
Avg. temp. Apr.	T2	0.6 +	0.1
Avg. temp. July	T3	0.8 +	0.4 +
Avg. temp. Oct.	T4	0.9 +	0.1
Avg. min. temp. Jan.	T5	0.7 +	-0.4 -
Avg. min. temp. April	T6	0.9 +	0.1
Avg. min. temp. July	T7	0.8 +	0.3 +
Avg. min. temp. Oct.	T8	0.9 +	-0.1
Avg. max. temp. Jan.	T9	0.8 +	-0.3 -
Avg. max. temp. April	T10	0.8 +	0.3 +
Avg. max. temp. July	T11	0.7 +	0.4 +
Avg. max. temp. Oct.	T12	0.9 +	0.1
No. of days temp. ⩾90° F in July	T15	-0.8 -	0.3 +
No. of days temp. ⩽32° F in April	T18	-0.9 -	0.1
No. of days temp. ⩽32° F in Oct.	T20	-0.8 -	0
Days since Jan. 1 to last day of 32°F or lower in spring	T22	0.9 +	0
Days since Jan. 1 to first day of 32°F or lower in fall	T23	-0.8 -	0
Heating degree days, 65°F Base	T24	0.9 +	0
Runs of ⩾ 5 days with max. temp. > 30°F Jan. 24-30	T25	-0.9 -	0
Runs of ⩾ 5 days with min. temp. ⩽ 50°F Sept. 20-26	T36	-0.4	0.6 +
Runs of ⩾ 5 days with max. temp. > 30°F March 1-7	T26	0.9 +	0
Runs of ⩾ 5 days with max. temp. > 30°F Dec. 27-Jan. 2	T27	0.9 +	0
Runs of ⩾ 5 days with max. temp. > 50°F March 22-28	T28	0.9 +	0
Runs of ⩾ 5 days with max. temp. > 50°F Nov. 8-14	T29	0.9 +	0
Runs of ⩾ 5 days with max. temp. > 90°F July 19-25	T30	-0.9 -	0
Runs of ⩾ 5 days with min. temp.			
⩽ 0°F Jan. 10-16	T31	-0.8 -	0.4 +
⩽ 0°F Feb. 21-27	T32	-0.9 -	0
Runs of ⩾5 days with min. temp. ⩽ 40°F April 26-May 2	T33	-0.9 -	0
Runs of ⩾ 5 days with min. temp. ⩽ 40°F Oct. 4-10	T34	-0.9 -	0.1
Runs of ⩾ 5 days with min. temp. ⩽ 50°F May 24-30	T35	-0.9 -	0

(Continued on next page)

(Table 2 continued)

PRECIPITATION

Variable	Variable codes[1]	Factor code		
		LSP48[2]	LSP21[2]	LSP12[2]
Avg. annual total precipitation in inches	P1	0.6 +	-0.2	0.4 +
Avg. annual total number of days		0.8 +	0	0
precipitation > 0.1″	P2	0.8 +	-0.2	0
Avg. total precipitation in Jan.	P3	0.6 +	-0.6 -	0.1
Avg. total precipitation in April	P4	-0.1	0.1	0.8
Avg. total precipitation in July	P5	0.8 +	-0.2	0.1
Avg. total precipitation in Oct.	P6			
Avg. total number of days with precipitation > 0.1″ in Jan.	P7	0.8 +	-0.1	-0.2
Avg. total number of days with precipitation ⩾ 0.1″ percent in April	P8	0.7 +	-0.5 -	0
Avg. total number of days with precipitation ⩾ 0.1″ percent in July	P9	0	0.3	0.7 +
Avg. total number of days with precipitation ⩾ 0.1″ percent in Oct.	P10	0.8 +	0	0.1
Avg. annual total snowfall in inches	P11	0.6 +	0.6 +	0
Avg. total snowfall in April	P13	0.1	0.8 +	0
Avg. total snowfall in Nov.	P14	0.4	0.7 +	0

SOLAR RADIATION

Variable	Variable codes[1]	Factor code	
		LSR63[2]	LSR29[2]
Potential solar radiation Jan.	R2	0.9 +	-0.2
Potential solar radiation April	R3	0.9 +	-0.2
Potential solar radiation July	R4	0.9 +	-0.2
Potential solar radiation Oct.	R5	0.9 +	-0.2
Mean monthly percent possible sunshine Jan.	R6	0	0.8 +
Potential solar radiation - annual	R11	0.9 +	-0.2
Mean annual total hours of sunshine,	R8	0.4	0.7 +
Mean annual number of clear days, sunrise to sunset	R9	0.3	0.8 +
Mean annual pan evaporation (inches)	R10	0.7 +	0.4

[1] Component Code Legend: LS = Lake State, T, P, R = Temperature, Precipitation, Radiation 79, 07, 48, 21, 12, 63, 29 = Proportion of variation accounted for by that component.

[2] Factor Code Legend: LS = Lake States; T = temperature; P = precipitation; and R = solar radiation; and the numbers = percent of variation accounted for.

[3] Variables with a + or –beside the factor pattern value are influential (positively or negatively) in determining component measuring.

summer (LSP12), whereas homoclime 12 experiences high annual precipitation, most of which comes in the winter. Homoclimes 18 and 12 both receive more precipitation than the regional median, but 18 receives 13 percent of the annual total precipitation in July, the highest in the region, whereas homoclime 12 receives only 8 percent of its annual total precipitation in July, sharing a regional low with homoclimes 11, 6, and 2. Homoclime 18 stands out as being very different in this respect than any other homoclime in the region.

Total annual potential solar radiation and pan evaporation are high in homoclimes 16, 19, 8, and 1 and low in homoclimes 13 and 10 (LSR63). Homoclime 8 is dramatically isolated as having the largest number of clear days in the year (LSR29) while homoclime 7 experiences the most cloudiness annually. Homoclime 7 receives only 25 percent of the mean annual possible sunshine while homoclime 8 receives 55 percent. To further emphasize the difference, homoclime 7 has less potential solar radiation incoming than does homoclime 8.

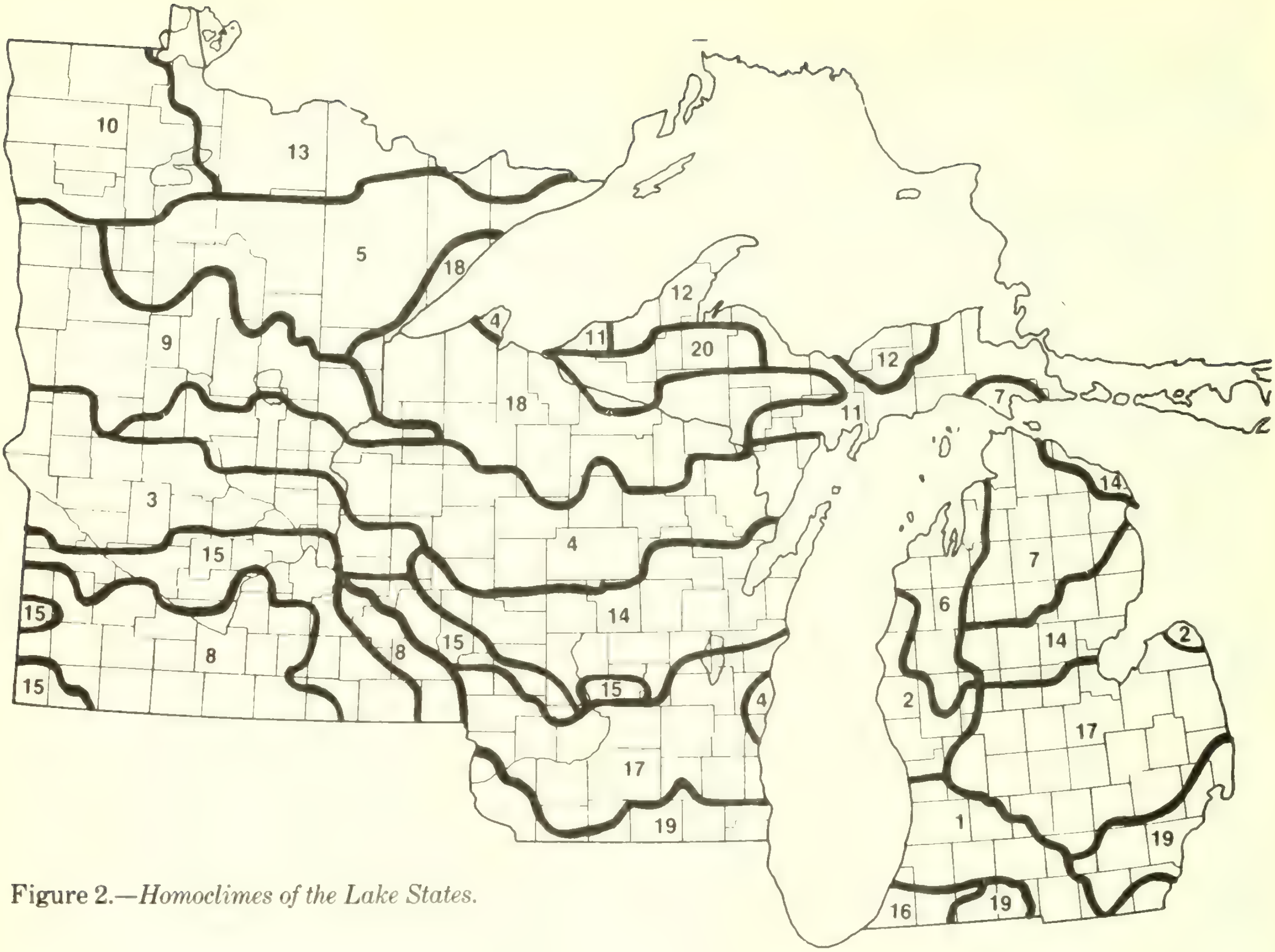

Figure 2.—*Homoclimes of the Lake States.*

Appendix C contains a detailed profile of each homoclime as it is related in multidimensional space to all other homoclimes. The profile plots in Appendix C place similar homoclimes in adjacent positions and dissimilar homoclimes in distant positions based upon euclidean distances obtained from the cluster analysis. Furthermore, for each homoclime some key explanatory variables are presented along with summary statistics for them. These homoclime summaries are intended to provide a quick overview of the salient features of the particular homoclime in question.

SUMMARY

To collate and summarize the characteristics of the climate of the Lake States region, 20 homoclimes have been defined and mapped. The homoclimes have been analyzed, quantitatively described, and compared with each other. The major patterns of temperature, precipitation, and radiation have been described.

It should be understood that in a study of this kind the normal or average characteristics are used. In attempts to relate vegetative composition or dynamics to these homoclimes, the variations of the climatic factors around their normal values must be taken into account. Additional variation will also be introduced by the differential influence of specific sites on the homoclimatic averages. Microclimates within each homoclime should be investigated, stratitified, and related quantitatively to the homoclimatic averages.

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Table 3.—*Profile plot of the seven principal components (LST9, LST07, LSP48, LSP21, LSP12, LSR63, LSR24) based on median scores for each homoclime (1-20) on each component*

Principal component	Minimum value	Homoclimes relative to each other				Maximum value
LST79[1]	–31	13. .10.05.20	18.12.11.04.07 .09. . .	03.14.06.15.02 08	17. . .01.16 . . .19.	65
LST07	–8	11.12.07.01.16[2] .06. .19.17 .02. . .20	.18.04. . .14.	. .05.13.08 . . .15.03 09	. . . .10	3
LSP48	–9	10.03.08.15. . .09.	05.04.14.18.19 13. . .17.	. . .07.01 . . . .11 02	06.16. . .12 .20.	19
LSP21	–5	19.16.01. .02 . .17. .14	.15.04.06.07 .08.03.09.18	10.05.11. . . .13. .	. .20. .12	10
LSP12	–3	12. .06.02.10 . . .11.07	03.09.15.14.16 01. .08.17.	13.05.20.04. .19. . .	. .18.	3
LSR63	–10	13.10. .12. . . .05. . . .11. . . .20.	18. .09.07.04	.06.14.02. .03.	15. .08.19.16 17. .01.	10
LSR29	–5	07. .06.11.20 . .02.12.01 16	19.18. .17.04 . . . .14	05.13. .09.15 . . . .03 10	. . .08.	5

[1] Component Code Legend: LS = Lake State, T, P, R = Temperature, Precip Radiation 79, 07, 48, 21, 12, 63, 29 = Proportion of variation accounted for by component.

[2] Homoclimes 16, 17, and 20 hold the same relative position across component LST07.

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Appendix A.—Listing of variables used and their sources

TEMPERATURE

Variable	Variable code	Reference		
		MI	MN	WI
Avg. temp. Jan.	T1	19/B1/M[1]	4/8/M	35/6-14/R
Avg. temp. Apr.	T2	19/B4/M	4/9/M	35/6-14/R
Avg. temp. July	T3	19/B7/M	4/10/M	35/6-14/R
Avg. temp. Oct.	T4	19/B10/M	4/4/M	35/6-14/R
Avg. min. temp. Jan.	T5	22/E1/M	4/12/M	35/6-14/R
Avg. min. temp. April	T6	22/E4/M	4/16/M	35/6-14/R
Avg. min. temp. July	T7	22/E7/M	4/17/M	35/6-14/R
Avg. min. temp. Oct.	T8	22/E10/M	4/19/M	35/6-14/R
Avg. max. temp. Jan.	T9	21/D1/M	4/12/M	35/6-14/R
Avg. max. temp. April	T10	21/D4/M	4/15/M	35/6-14/R
Avg. max. temp. July	T11	21/D7/M	4/17/M	35/6-14/R
Avg. max. temp. Oct.	T12	21/D10/M	4/18/M	35/6-14/R
No. of days temp. ⩾ 90°F in July	T15	33/*/R	34/*/R	35/6-14/R
No. of days temp. ⩽ 32°F in April	T18	33/*/R	34/*/R	35/6-14/R
No. of days temp. ⩽ 32°F in Oct.	T20	33/*/R	34/*/R	35/6-14/R
Days since Jan. 1 to last day of 32°F or lower in spring	T22	25/5/R	2/14/M	37/6/M
Days since Jan. 1 to first day of 32°F or lower in fall	T23	5/5/R	2/15/M	37/7/M
Heating degree days, 65°F Base	T24	24/F13/M	6/68/M	6/68/M
Run of > 5 days with max. temp. > 30°F Jan. 24-30	T25	12/8/M	10/8/M	10/8/M
Run of ⩾ 5 days with min. temp. ⩽ 50°F Sept. 20-26	T36	10/68/M	10/71/M	10/68/M
Runs of ⩾ 5 days with max. temp. < 30°F March 1-17	T26	10/9/M	10/9/M	10/9/M
Runs of ⩾ 5 days with max. temp. > 30°F Dec. 27-Jan. 2	T27	10/10/M	10/10/M	10/10/M
Runs of ⩾ 5 days with max. temp. > 50°F March 22-28	T28	10/29/M	10/29/M	10/29/M
Runs of ⩾ 5 days with max. temp. > 50°F Nov. 8-14	T29	10/31/M	10/31/M	10/31/M
Runs of ⩾ 5 days with max. temp. > 90°F July 19-25				
Runs of ⩾ 5 days with min. temp. < 0°F Jan. 10-16	T31	10/44/M	10/44/M	10/44/M
Runs of ⩾ 5 days with max. temp. ⩽ 0°F Feb. 21-27	T32	10/45/M	10/45/M	10/45/M
Runs of ⩾ 5 days with min. temp. ⩽ 40°F April 26-May 2	T33	10/57/M	10/57/M	10/57/M
Runs of ⩾ 5 days with min. temp. ⩽ 40°F Oct. 4-10	T34	10/58/M	10/58/M	10/58/M
Run of ⩾ 5 days with min. temp. ⩽ 50°F May 24-30	T35	10/67/M	10/67/M	10/67/M

PRECIPITATION

Variable	Variable code	MI	MN	WI
Avg annual total precipitation in inches	P1	18/A13/M	5/12/M	49/6-14/R
Avg. annual total number of days precipitation > 0.1"	P2	23/L13/M	6/71/M	49/6-14/R
Avg. total precipitation in Jan. in inches	P3	18/A1/M	5/16/M	49/6-14/R
Avg. total precipitation in April in inches	P4	18/A4/M	5/16/M	49/6-14/R
Avg. total precipitation in July in inches	P5	18/A7/M	5/17/M	49/6-14/R
Avg. total precipitation in Oct. in inches	P6	8/A10/M	5/18/M	49/6-14/R
Avg. total number of days with precipitation > 0.1" in Jan.	P7	23/L1/M	34/*/R	49/6-14/R
Avg. total number of days with precipitation ⩾ 0.1" pct. in April	P8	23/L4/M	34/*/R	49/6-14/M
Avg. total number of days with precipitation ⩾ 0.1" pct. in July	P9	23/L7/M	35/*/R	49/6-14/R
Avg. total number of days with precipitation ⩾ 0.1" pct. in Oct.	P10	23/L10/M	34/*/R	49/6-14/R
Avg. annual total snowfall in inches	P11	17/17/M	5/30/M	49/6-14/R
Avg. total snowfall in Jan. in inches	P12	20/C1/M	34/*/R	49/6-14/R
Avg. total snowfall in April in inches	P13	21/C4/M	34/*/R	49/6-14/R
Avg. total snowfall in Nov. in inches	P14	20/C11/M	34/*/R	49/6-14/R

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(Appendix A continued)

SOLAR RADIATION

Potential solar radiation Jan.	R2	12/*/M	12/*/M	12/*/M
Potential solar radiation April	R3	12/*/M	12/*/M	12/*/M
Potential solar radiation July	R4	12/*/M	12/*/M	12/*/M
Potential solar radiation Oct.	R5	12/*/M	12/*/M	12/*/M
Mean monthly pct. possible sunshine Jan.	R6	36/22/M	6/97/M	6/99/M
Potential solar radiation - annual, 1000's of Langleys	R11	12/*/M	12/*/M	12/*/M
Mean annual total hours of sunshine	R8	36/25/M	6/102/M	6/101/M
Mean annual number of clear days, sunrise to sunset	R9	6/110/M	6/101/M	6/61/M
Mean annual pan evaporation (inches)	R10	6/97/M	6/110/M	6/97/M

[1] Reference code 19/B1/M: 19=reference number (Michigan Department of Agriculture 1974); B1=page no. (*=no page number); and M=iso bar or R=raw data.

Appendix B.—Median values for all variables (rows) across all homoclimes and the Lake States regional average

TEMPERATURE

Variable	Variable code	Homoclime number					
		13	10	5	18	20	9
Avg. temp. Jan.	T1	4	3	7	12	13	8
Avg. temp. Apr.	T2	37	39	39	40	39	42
Avg. temp. July	T3	66	68	67	66	65	70
Avg. temp. Oct.	T4	42	44	44	46	46	46
Avg. min. temp. Jan.	T5	- 6	- 7	- 2	1	3	- 3
Avg. min. temp. April	T6	26	28	26	28	27	30
Avg. min. temp. July	T7	52	55	55	54	52	58
Avg. min. temp. Oct.	T8	32	32	33	34	35	34
Avg. max. temp. Jan.	T9	15	14	18	23	22	18
Avg. max. temp. April	T10	49	50	51	52	52	53
Avg. max. temp. July	T11	78	80	80	79	79	83
Avg. max. temp. Oct.	T12	53	55	55	57	57	57
No. of days temp. ⩾ 90°F in July	T15	0	2	0	1	1	3
No. of days temp ⩽ 32°F in April	T18	22	22	22	19	21	19
No. of days temp ⩽ 32°F in Oct.	T20	17	16	15	14	14	13
Days since Jan. 1 to last day of 32°F or lower in spring	T22	150	150	150	148	155	143
Days since Jan. 1 to first day of 32°F or lower in fall	T23	262	262	262	260	258	267
Heating degree days, 65°F Base	T24	10,500	9,500	9,500	9,200	9,200	9,500
Runs of ⩾ 5 days with max. temp. > 30°F Jan. 24-30	T25	10	10	15	15	15	15
Runs of ⩾ 5 days with ⩽ 50°F Sept. 20-26	T36						
Runs of ⩾ 5 days with max. temp. < 30°F March 1-7	T26	40	40	40	45	45	40
Runs of ⩾ 5 days with max. temp. > 30°F Dec. 27-Jan. 2	T27	10	10	20	17	15	30
Runs of ⩾ 5 days with max. temp. > 50°F March 22-28	T28	10	10	15	15	10	20

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(Appendix B continued)

Runs of ≥ 5 days with max. temp. > 50°F Nov. 8-14	T29	10	10	10	10	10	15
Runs of ≥ 5 days with max. temp. > 90°F July 19-25	T30	10	10	10	5	5	15
Runs of ≥ 5 days with min. temp. ≤ 0°F Jan. 10-16	T31	60	60	40	30	25	40
Runs of ≥ 5 days with min. temp. ≤ 0°F Feb. 21-27	T32	20	20	20	11	12	20
Runs of ≥ 5 days with min. temp. ≤ 40°F April 26-May 2	T33	60	60	60	60	65	50
Runs of ≥ 5 days with min. temp. ≤ 40°F Oct. 4-10	T34	50	50	50	40	45	45
Runs of ≥ 5 days with min. temp. ≤ 50°F May 24-30	T35	60	60	60	55	65	50
PRECIPITATION							
Avg. annual total precipitation in inches	P1	26	20	26	31	33	24
Avg. annual total number of days precipitation > 0.1"	P2	135	115	135	125	150	105
Avg. total precipitation in Jan.	P3	0.8	0.6	0.8	1.1	1.5	0.7
Avg. total precipitation in April	P4	1.8	1.5	2.1	2.5	2.5	2.2
Avg. total precipitation in July	P5	3.5	3.1	3.6	4.0	3.7	3.2
Avg. total precipitation in Oct.	P6	1.7	1.3	1.8	2.1	2.2	1.5
Avg. total number of days with precipitation > 0.1" in Jan.	P7	3	3	3	3	6	2
Avg. total number of days with precipitation ≥ 0.1" pct. in April	P8	5	3	4	6	6	5
Avg. total number of days with precipitation ≥ 0.1" pct. in July	P9	7	6	7	7	7	6
Avg. total number of days with precipitation ≥ 0.1" pct. in Oct.	P10	5	4	4	5	6	3
Avg. annual total snowfall in inches	P11	55	40	55	54	110	45
Avg. total snowfall in Jan.	P12	11	8	10	11	22	7
Avg. total snowfall in April	P13	6.0	3.0	5.0	4.4	7.5	4.0
Avg. total snowfall in Nov.	P14	8.0	7.0	8.0	8.0	21.0	6.0
SOLAR RADIATION							
Potential solar radiation Jan.	R2	53	52	56	60	59	60
Potential solar radiation April	R3	221	220	223	225	224	225
Potential solar radiation July	R4	299	299	300	300	300	300
Potential solar radiation Oct.	R5	118	117	121	125	124	125
Mean monthly pct. possible sunshine, Jan.	R6	45	45	45	40	35	45
Potential solar radiation - annual	R11	206	205	208	212	210	212
Mean annual total hours of sunshine	R8	2,500	2,500	2,500	2,300	2,200	2,500
Mean annual number of clear days, sunrise to sunset	R9	75	95	75	75	75	95
Mean annual pan evaporation (inches)	R10	30	35	30	32	32	40

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(Appendix B continued)

TEMPERATURE

Variable	Variable code	Homoclime number					
		11	12	4	7	3	14
Avg. temp. Jan.	T1	17	15	12	18	11	17
Avg. temp. Apr.	T2	39	39	42	41	44	44
Avg. temp. July	T3	65	64	70	66	72	70
Avg. temp. Oct.	T4	47	47	47	48	49	49
Avg. min. temp. Jan.	T5	8	8	3	9	1	8
Avg. min. temp. April	T6	29	29	31	29	32	32
Avg. min. temp. July	T7	53	53	57	53	60	58
Avg. min. temp. Oct.	T8	38	37	36	37	36	37
Avg. max. temp. Jan.	T9	24	22	23	26	21	26
Avg. max. temp. April	T10	49	49	54	53	55	55
Avg. max. temp. July	T11	76	76	82	80	84	82
Avg. max. temp. Oct.	T12	56	56	58	59	60	60
No. of days temp. $\geqslant$ 90°F in July	T15	1	1	2	2	4	
No. of days temp $\leqslant$ 32°F in April	T18	20	20	16	17	15	14
No. of days temp $\leqslant$ 32°F in Oct.	T20	8	8	11	11	11	10
Days since Jan. 1 to last day of 32°F or lower in spring	T22	145	145	137	156	133	130
Days since Jan. 1 to first day of 32°F or lower in fall	T23	268	278	271	258	272	271
Heating degree days, 65°F Base	T24	8,700	8,800	8,700	8,200	8,500	8,200
Runs of $\geqslant$ 5 days with max. temp. $>$ 30°F Jan. 24-30	T25	15	15	15	25	15	25
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 50°F Sept. 20-26	T36						
Runs of $\geqslant$ 5 days with max. temp. $>$ 30°F March 1-7	T26	45	45	50	55	50	55
Runs of $\geqslant$ 5 days with max. temp. $>$ 30°F Dec. 27-Jan. 2	T27	30	15	25	45	40	40
Runs of $\geqslant$ 5 days with max. temp. $>$ 50°F March 22-28	T28	10	10	15	17	30	17
Runs of $\geqslant$ 5 days with max. temp. $>$ 50°F Nov. 8-14	T29	10	7	15	12	20	15
Runs of $\geqslant$ 5 days with max. temp. $>$ 90°F July 19-25	T30	5	5	5	5	20	7
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 0°F Jan. 10-16	T31	7	25	25	5	30	15
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 0°F Feb. 21-27	T32	7	16	10	5	10	5
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 40°F April 26-May 2	T33	60	65	55	50	40	50
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 40° F Oct. 4-10	T34	35	45	30	25	40	25
Runs of $\geqslant$ 5 days with min. temp. $\leqslant$ 50°F May 24-30	T35	65	65	45	65	40	50

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(Appendix B continued)

			PRECIPITATION				
Avg. annual total precipitation in inches	P1	31	32	29	31	25	29
Avg. annual total number of days precipitation > 0.1"	P2	150	150	115	145	105	115
Avg. total precipitation in Jan.	P3	1.5	2.5	1.0	1.5	0.7	1.2
Avg. total precipitation in April	P4	2.5	2.5	2.4	2.5	2.2	2.6
Avg. total precipitation in July	P5	2.7	2.7	3.5	3.0	3.1	3.0
Avg. total precipitation in Oct.	P6	2.7	2.5	1.9	2.2	1.6	2.2
Avg. total number of days with precipitation > 0.1" in Jan.	P7	6	9	2	5	1	2
Avg. total number of days with precipitation ⩾ 0.1" percent in April	P8	6	6	5	6	5	6
Avg. total number of days with precipitation ⩾ 0.1" percent in July	P9	6	6	7	6	5	6
Avg. total number of days with precipitation ⩾ 0.1" percent in Oct.	P10	7	6	5	6	4	5
Avg. annual total snowfall in inches	P11	95	135	46	75	40	45
Avg. total snowfall in Jan.	P12	24	35	10	21	7	10
Avg. total snowfall in April	P13	3.5	6.7	3.0	4.0	3.0	1.9
Avg. total snowfall in Nov.	P14	15.0	21.0	5.5	10.0	5.0	4.5
			SOLAR RADIATION				
Potential solar radiation Jan.	R2	59	57	64	66	65	68
Potential solar radiation April	R3	224	223	228	228	228	230
Potential solar radiation July	R4	300	300	301	301	301	302
Potential solar radiation Oct.	R5	124	122	129	131	130	133
Mean monthly percent possible sunshine Jan.	R6	35	35	45	25	55	45
Potential solar radiation - annual	R11	211	209	215	216	216	218
Mean annual total hours of sunshine	R8	2,100	2,100	2,400	2,200	2,500	2,400
Mean annual number of clear days, sunrise to sunset	R9	75	75	85	75	95	85
Mean annual pan evaporation (inches)	R10	32	31	37	32	40	37

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(Appendix B continued)

TEMPERATURE

Variable	Variable code	Homoclime number 6	15	2	8	17	1
Avg. temp. Jan.	T1	20	14	21	14	21	23
Avg. temp. Apr.	T2	43	45	44	46	46	47
Avg. temp. July	T3	68	73	69	74	71	71
Avg. temp. Oct.	T4	49	50	50	51	51	52
Avg. min. temp. Jan.	T5	13	4	15	5	13	16
Avg. min. temp. April	T6	31	34	34	35	35	36
Avg. min. temp. July	T7	55	61	57	61	59	60
Avg. min. temp. Oct.	T8	39	38	41	39	40	41
Avg. max. temp. Jan.	T9	29	24	29	24	29	31
Avg. max. temp. April	T10	53	56	56	57	57	58
Avg. max. temp. July	T11	80	85	82	86	83	82
Avg. max. temp. Oct.	T12	59	62	61	63	62	63
No. of days temp. ⩾ 90°F in July	T15	3	6	2	7	4	5
No. of days temp. ⩽ 32°F in April	T18	15	13	13	13	12	10
No. of days temp. ⩽ 32°F in Oct.	T20	8	10	7	10	7	6
Days since Jan. 1 to last day of 32°F Or lower in spring	T22	145	130	135	130	127	125
Days since Jan. 1 to first day of 32°F or lower in fall	T23	268	277	278	277	278	278
Heating degree days, 65°F Base	T24	7,700	8,000	7,200	7,500	7,200	6,700
Runs of ⩾ 5 days with max. temp. > 30°F Jan. 24-30	T25	30	20	35	20	35	35
Runs of ⩾ 5 days with min. temp. ⩽ 50°F Sept. 20-26	T36						
Runs of ⩾ 5 days with max. temp. > 30°F March 1-7	T26	60	60	70	60	70	82
Runs of ⩾ 5 days with max. temp. 30°F Dec. 27-Jan. 2	T27	45	45	50	50	55	55
Runs of ⩾ 5 days with max. temp. > 50°F March 22-28	T28	17	30	17	35	20	35
Runs of ⩾ 5 days with max. temp. > 50°F Nov. 8-14	T29	15	20	17	30	17	25
Runs of ⩾ 5 days with max. temp. > 90°F July 19-25	T30	7	30	7	30	10	10
Runs of ⩾ 5 days with min. temp. ⩽ 0°F Jan. 10-16 T31	5	25	5	20	10	5	
Runs of ⩾ 5 days with min. temp. ⩽ 0°F Feb. 21-27	T32	5	5	5	5	5	5
Runs of ⩾ 5 days with min. temp. ⩽ 40°F April 26-May 2	T33	47	40	45	30	45	42
Runs of ⩾ 5 days with min. temp. ⩽ 40°F Oct. 4-10	T34	25	25	17	20	17	17
Runs of ⩾ 5 days with min. temp. ⩽ 50°F May 24-30	T35	55	30	52	20	40	35

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(Appendix B continued)

		PRECIPITATION					
Avg. annual total precipitation in inches	P1	31	28	31	28	30	33
Avg. annual total number of day precipitation > 0.1″	P2	145	105	145	105	120	145
Avg. total precipitation in Jan.	P3	1.5	0.8	2.0	0.7	1.4	2.0
Avg. total precipitation in April	P4	3.0	2.2	3.0	2.1	2.7	3.2
Avg. total precipitation in July	P5	2.7	3.5	2.7	3.2	3.0	3.0
Avg. total precipitation in Oct.	P6	2.7	1.6	2.7	1.6	2.2	2.7
Avg. total number of days with precipitation > 0.1″ in Jan.	P7	6	1	6	1	3	6
Avg. total number of days with precipitation ⩾ 0.1″ percent in April	P8	7	5	7	4	7	7
Avg. total number of days with precipitation ⩾ 0.1″ percent in July	P9	5	6	6	6	6	5
Avg. total number of days with precipitation ⩾ 0.1″ percent in Oct.	P10	6	4	6	4	5	6
Avg. annual total snowfall in inches	P11	75	40	65	40	40	45
Avg. total snowfall in Jan.	P12	25	7	22	7	10	13
Avg. total snowfall in April	P13	3.2	2.0	1.5	2.0	1.5	1.5
Avg. total snowfall in Nov.	P14	10.0	5.0	6.0	5.0	3.5	6.0
		SOLAR RADIATION					
Potential solar radiation Jan.	R2	68	69	71	71	73	77
Potential solar radiation April	R3	230	231	232	232	233	235
Potential solar radiation July	R4	302	302	302	302	303	303
Potential solar radiation Oct.	R5	133	134	136	136	138	141
Mean monthly percent possible sunshine, Jan.	R6	25	55	25	55	45	35
Potential solar radiation - annual	R11	218	219	221	221	222	225
Mean annual total hours of sunshine	R8	2,300	2,500	2,400	2,700	2,400	2,400
Mean annual number of clear days, sunrise to sunset	R9	85	95	85	115	85	85
Mean annual pan evaporation (inches)	R10	33	45	37	45	37	37

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(Appendix B continued)

TEMPERATURE

Variable	Variable code	Homoclime number 19	16	Lake States regional average
Avg. temp. Jan.	T1	23	24	14
Avg. temp. Apr.	T2	47	48	43
Avg. temp. July	T3	72	72	70
Avg. temp. Oct.	T4	52	53	48
Avg. min. temp. Jan.	T5	15	17	4
Avg. min. temp. April	T6	36	37	31
Avg. min. temp. July	T7	61	61	58
Avg. min. temp. Oct.	T8	41	43	37
Avg. max. temp. Jan.	T9	30	32	24
Avg. max. temp. April	T10	58	59	54
Avg. max. temp. July	T11	83	84	82
Avg. max. temp. Oct.	T12	64	64	59
No. of days temp. ⩾ 90°F in July	T15	6	6	3
No. of days temp. ⩽ 32°F in April	T18	9	9	16
No. of days temp. ⩽ 32°F in Oct.	T20	5	3	11
Days since Jan. 1 to last day of 32°F or lower in spring	T22	125	125	135
Days since Jan. 1 to first day of 32°F or lower in fall	T23	281	288	271
Heating degree days, 65°F Base	T24	6,700	6,200	8,500
Runs of ⩾ 5 days with max. temp. >30°F Jan. 24-30	T25	35	40	20
Runs of ⩾ 5 days with min. temp. ⩽ 50°F Sept. 20-26	T36			
Runs of ⩾ 5 days with max. temp. <30°F March 1-7	T26	80	85	50
Runs of ⩾ 5 days with max. temp. > 30°F Dec. 27-Jan. 2	T27	60	65	35
Runs of ⩾ 5 days with max. temp. > 50°F March 22-28	T28	30	40	17
Runs of ⩾ 5 days with max. temp. > 50°F Nov. 8-14	T29	30	35	15
Runs of ⩾ 5 days with max. temp. > 90°F July 19-25	T30	15	15	10
Runs of ⩾ 5 days with min. temp. ⩽ 0°F Jan. 10-16	T31	5	5	20
Runs of ⩾ 5 days with min. Temp. ⩽ 0°F Feb. 21-27	T32	5	5	7
Runs of ⩾ 5 days with min. temp. ⩽ 40°F April 26-May 2	T33	35	35	50
Runs of ⩾ 5 days with min. temp. ⩽ 40°F Oct. 4-10	T34	15	15	30
Runs of ⩾5 days with min. temp. ⩽ 50°F May 24-30	T35	35	30	50

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(Appendix B continued)

PRECIPITATION				
Avg. annual total precipitation in inches	P1	32	35	29
Avg. annual total number of days precipitation > 0.1″	P2	145	145	115
Avg. total precipitation in Jan.	P3	1.5	2.5	1.0
Avg. total precipitation in April	P4	3.2	3.7	2.5
Avg. total precipitation in July	P5	3.5	3.2	3.2
Avg. total precipitation in Oct.	P6	2.4	3.2	2.0
Avg. total number of days with precipitation > 0.1″ in Jan.	P7	4	6	3
Avg. total number of days with precipitation ⩾ 0.1″ percent in April	P8	7	7	5
Avg. total number of days with precipitation ⩾ 0.1″ percent in July	P9	6	6	6
Avg. total number of days with precipitation ⩾ 0.1″ percent in October	P10	5	6	5
Avg. annual total snowfall in inches	P11	35	45	45
Avg. total snowfall in Jan.	P12	9	13	10
Avg. total snowfall in April	P13	1.2	1.5	3.0
Avg. total snowfall in Nov.	P14	3.0	6.0	6.0
SOLAR RADIATION				
Potential solar radiation Jan.	R2	77	80	65
Potential solar radiation April	R3	235	236	228
Potential solar radiation July	R4	303	304	301
Potential solar radiation Oct.	R5	141	144	130
Mean monthly percent possible sunshine, Jan.	R6	35	35	45
Potential solar radiation - annual	R11	225	227	216
Mean annual total hours of sunshine	R8	2,500	2,500	2,500
Mean annual number of clear days, sunrise to sunset	R9	85	85	85
Mean annual pan evaporation (inches)	R10	42	40	37

APPENDIX C

This appendix contains a detailed profile of each homoclime. Section I displays the relation between a given homoclimatic zone and all others. Zones at the left margin of the profile plot are highly similar to the zone under discussion using euclidean distances obtained from the cluster analysis as the metric. Highly similar zones have similar euclidean distances with the zone under discussion; highly dissimilar zones are further away in euclidean space.

Section II presents the minimum, median, and maximum values and the standard deviation and coefficient of variation for key explanatory variables. The Lake States medium values for the key explanatory variables are also given for comparison. The key explanatory variables are as follows:

T5 = average minimum January temperature, °F;
T11= average maximum July temperature, °F;
P12= average total snowfall in January, inches;
P13= average total snowfall in April, inches;
P14= average total snowfall in November, inches;
P5 = average total precipitation in July, inches;
P3 = average total precipitation in January, inches;
P1 = average annual total precipitation, inches;
R11= potential, extraterrestrial, normal radiation, 1,000 langleys;
R10= mean annual pan evaporation, inches; and
R6 = mean monthly percent possible sunshine, January.

HOMOCLIME 1

I. PROFILE PLOT

```
MIN.                                                                MAXIMUM
VALUE               HOMOCLIMES RELATIVE TO EACH OTHER               VALUE

  10 | 01.19.17.  .  | 06.14.15.07.03 | 04.11.   . 12.18 | 20.05.  .10.13 |   91
     |    .  .16.    | 08.  .  .  .   |    .  .  . 09.   |    .  .  .  .  |
     |    .  .02.  . |    .  .  .  .  |    .  .  .  .    |    .  .  .  .  |
     |                                                                   |
     | Highly Similar <-----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	15	16	19	1.3	7	4
Avg. Max. Jul (T11)	79	82	84	1.3	1	82
(T11 -T5)	--	66	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	9	13	23	4.6	30	10
Apr (P13)	0.5	1.5	2.5	0.5	30	3
Nov (P14)	3	6	10	2.0	30	6
Avg. Total PPT:						
Jul (P5)	2.7	3	3.7	0.3	11	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	8	--	--	--	--
Jan [(P3/P1).100)]	--	6	--	--	--	--
Radiation						
Radiation (R11)(*)	223	225	228	1.5	1	216
Evaporation (R10)(in.)	32	37	42	3.0	7	37
Percent Sunshine Jan (R6)	30	35	35	1.0	3	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 2

I. PROFILE PLOT

```
MIN.                                                                  MAXIMUM
VALUE              HOMOCLIMES RELATIVE TO EACH OTHER                  VALUE

  10 | 02.06.17.01.14 | 07.15.   .03.11 | .12.18. 20.  | 05.  .  .10.13 |  74
     |   .   .   .    |   .19 . .16.    |  .  .09.   . |  .   .  .  .  |
     |   .   .   .  . |   .08 . .04.    |  .  .  .   . |  .   .  .  .  |
     |
     | Highly Similar <-----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	13	15	17	1.5	10	4
Avg. Max. Jul (T11)	80	82	84	1.4	1.8	82
(T11 -T5)	--	67	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	11	22	28	5.7	28	10
Apr (P13)	1.5	1.5	2.5	.27	17	3
Nov (P14)	4	6	8	.99	15	6
Avg. Total PPT:						
Jul (P5)	2.5	2.7	3.5	0.3	10	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	8.9	--	--	--	--
Jan [(P3/P1).100)]	--	6.3	--	--	--	--
Radiation						
Radiation (R11)(*)	218	221	222	1.3	.6	216
Evaporation (R10)(in.)	35	37	38	1.2	3.2	37
Percent Sunshine Jan (R6)	25	25	35	2.9	11	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 3

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	03.15. .04.	09.07.06.11.17	02. .05. 20.12	. . .13.16	59
	. . .14.	.08. . .18	. . . 10.19	. . . .	
	. .02. .	. . . . .	01	. . . .	

Highly Similar <-----------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-5	1	4.5	1.9	206	4
Avg. Max. Jul (T11)	82	84.5	87	1.0	1.2	82
(T11 -T5)	--	83.5	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	7	9	0.8	10	10
Apr (P13)	1.7	3	5	.79	26	3
Nov (P14)	4	5	6	.64	12	6
Avg. Total PPT:						
Jul (P5)	2.8	3.1	4	.22	7.1	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	12	--	--	--	--
Jan [(P3/P1).100)]	--	3	--	--	--	--
Radiation						
Radiation (R11)(*)	213	216	217	1.1	.54	216
Evaporation (R10)(in.)	37	40	45	2.6	6.2	37
Percent Sunshine Jan (R6)	45	55	55	4.2	8.0	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 4

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	04. .14.11.18	15. .05.12.02	08. . . 13.	01. . . .16	91
	. .03.09	06. .20. .	17. . . .	19. . . .	
	. .07. .	. . . .	10. . . .	. . . .	

Highly Similar <------------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-5	3	12	2.9	88	4
Avg. Max. Jul (T11)	76	82	85	2.0	2.5	82
(T11 -T5)	--	79	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	10	14	2.3	23	10
Apr (P13)	0.5	3	6	0.8	26	3
Nov (P14)	2 5	5.5	9	1.1	21	6
Avg. Total PPT:						
Jul (P5)	2.5	3.5	5.5	.6	16	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	11.9	--	--	--	--
Jan [(P3/P1).100)]	--	3.4	--	--	--	--
Radiation						
Radiation (R11)(*)	209	215	222	1.7	.8	216
Evaporation (R10)(in.)	33	37	40	2.7	7.5	37
Percent Sunshine Jan (R6)	25	45	55	2.8	6.4	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 5

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	05.18.13.09.11	04. .07.14.	06. .02. 08.17	.01.19. .16	91
	.10.20.	12. .03. .	15. . . .	. . . .	
	. . . .	. . . .	. . . .	. . . .	
	Highly Similar <------------------------------> Highly Dissimilar				

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-6	-2.5	6	2.7	-107	4
Avg. Max. Jul (T11)	69	80	87	2.9	3.7	82
(T11 -T5)	--	82	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	7	10	13	1.4	14	10
Apr (P13)	3	5	8	1.3	27	3
Nov (P14)	4	8	8	.52	12	6
Avg. Total PPT:						
Jul (P5)	2.8	3.6	4.5	.17	8.2	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	14	--	--	--	--
Jan [(P3/P1).100)]	--	3.4	--	--	--	--
Radiation						
Radiation (R11)(*)	207	208	212	1.3	.64	216
Evaporation (R10)(in.)	30	30	35	2.4	7.5	37
Percent Sunshine Jan (R6)	35	45	45	1.3	2.9	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 6

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	06.14.02. . . .07.	17.15.03.08. 04.11.01.	12.18.20. 16.05 19.09.	. . .10.13	63

Highly Similar <-----------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	11	13	16	1.4	11	4
Avg. Max. Jul (T11)	80	80	82	.5	.6	82
(T11 -T5)	--	67	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	11	25	31	5.9	25	10
Apr (P13)	1.5	3.2	4	1.1	37	3
Nov (P14)	4	10	15	3.1	31	6
Avg. Total PPT:						
Jul (P5)	2.7	2.7	3.3	.2	5.3	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	9.0	--	--	--	--
Jan [(P3/P1).100)]	--	4.8	--	--	--	--
Radiation						
Radiation (R11)(*)	215	218	221	1.9	.9	216
Evaporation (R10)(in.)	30	33	38	2.5	7.3	37
Percent Sunshine Jan (R6)	25	25	25	0	0	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 7

I. PROFILE PLOT

```
MIN.                                                          MAXIMUM
VALUE           HOMOCLIMES RELATIVE TO EACH OTHER             VALUE

 10 | 07.  .11.04.  |    .02.  .15.09|17.05.08.   .01|10.19.13.  .16|  57
    |   .  .14.     |    .03.  .20.  |  .  .  .   .  |  .  .  .   .  |
    |   .  .06.  .  |    .18 . .  .  |  .  .  .   .  |  .  .  .   .  |
    |               |    .12                                        |
    | Highly Similar <----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	7.5	9	11.5	1.0	11	4
Avg. Max. Jul (T11)	76	80	82	1.5	2.0	82
(T11 -T5)	--	71	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	18	21	35	4.7	21	10
Apr (P13)	2.5	4	5	0.6	15	3
Nov (P14)	6	10	20	0.9	36	6
Avg. Total PPT:						
Jul (P5)	2.3	3	4	0.4	14	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	9.7	--	--	--	--
Jan [(P3/P1).100)]	--	4.8	--	--	--	--
Radiation						
Radiation (R11)(*)	212	216	218	1.8	0.8	216
Evaporation (R10)(in.)	33	32	38	1.6	4.6	37
Percent Sunshine Jan (R6)	25	25	35	2.0	7.6	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 8

I. PROFILE PLOT

```
MIN.                                                                    MAXIMUM
VALUE                  HOMOCLIMES RELATIVE TO EACH OTHER                VALUE

   10 | 08.15.  .17.19 | 03.02.  .04.07 |  .09.11.   .18 | 12.20.10.  .13 |  77
      |   .   .   .    | 14.01.  .  .16 |   .   .   .   . |  .05.   .   .  |
      |   .   .   .   .|  .06 .  .   .  |   .   .   .   . |   .   .   .   .|
      |                    .                                              |
      | Highly Similar <-------------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-6	5	7.5	3.6	92	4
Avg. Max. Jul (T11)	84	86	87	.8	.9	82
(T11 -T5)	--	81	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	5	7	9	.89	13	10
Apr (P13)	2	2	3	.36	17	3
Nov (P14)	4	5	6	.52	10	6
Avg. Total PPT:						
Jul (P5)	2.8	3.2	3.8	.28	8.9	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	12	--	--	--	--
Jan [(P3/P1).100)]	--	2.7	--	--	--	--
Radiation						
Radiation (R11)(*)	219	221	222	.9	.4	216
Evaporation (R10)(in.)	45	45	50	2.5	5.3	37
Percent Sunshine Jan (R6)	55	55	55	0	0	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 9

I. PROFILE PLOT

```
 MIN.                                                              MAXIMUM
 VALUE              HOMOCLIMES RELATIVE TO EACH OTHER              VALUE

 10 | 09.  .  .04.10 | 11.20.13.12.06 | 08.  .02.   .  | .01.  .  .16 |   78
    |  .   .  .18.   |  .07.15.  .    |  .   .17.   .  | .19.  .  .   |
    |  .   .  .05.   |  .14 .  .  .   |  .   .   .   . |  .   .  .  . |
    |                |  .03                                           |
    | Highly Similar <------------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-8	-3	--	1.8	-66	4
Avg. Max. Jul (T11)	80	83	85	1.2	1.5	82
(T11 -T5)	--	86	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	7	11	1.4	19	10
Apr (P13)	1	4	5	1.0	28	3
Nov (P14)	4	6	8	0.9	15	6
Avg. Total PPT:						
Jul (P5)	2.1	3.2	4	0.3	10	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	13	--	--	--	--
Jan [(P3/P1).100)]	--	3	--	--	--	--
Radiation						
Radiation (R11)(*)	208	212	214	1.7	0.8	216
Evaporation (R10)(in.)	35	40	40	2.5	6.5	37
Percent Sunshine Jan (R6)	45	45	55	2.5	5.4	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 10

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	10.05.13.09.18	20.04.11.03.14	15.06. .08 .17	. .01. .16	98
	. . . . .	. . .12.	. . . . .	. .19. .	
	. . . . .	. . .07.	. . . . .	. . . . .	

Highly Similar <------------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-8	-7	-.8	1.4	-21	4
Avg. Max. Jul (T11)	80	80	83	1.0	1.3	82
(T11 -T5)	--	87	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	8	10	.9	12	10
Apr (P13)	1	3	4	1.0	40	3
Nov (P14)	5	7	8	.85	12	6
Avg. Total PPT:						
Jul (P5)	2.9	3.1	3.5	.2	5.9	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	14.8	--	--	--	--
Jan [(P3/P1).100)]	--	2.9	--	--	--	--
Radiation						
Radiation (R11)(*)	203	205	208	1.6	.8	216
Evaporation (R10)(in.)	30	35	35	2.3	6.8	37
Percent Sunshine Jan (R6)	45	45	45	0	0	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 11

I. PROFILE PLOT

```
MIN.                                                            MAXIMUM
VALUE              HOMOCLIMES RELATIVE TO EACH OTHER            VALUE

  10 | 11.  .07.20.  | 14.05.03.  .02 | 15.  .17.08 .  | 01.  .19.  .16 |  69
     |  .   .18.04.  | 06.09.   .   . | 10.   .   .  . |  .   .   .  .  |
     |  .   .12.  .  |  .   .   .   . | 13.   .   .  . |  .   .   .  .  |
     |                                                                  |
     | Highly Similar <-----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	6	8	12	1.5	18	4
Avg. Max. Jul (T11)	75	76	79	1.0	1.2	82
(T11 -T5)	--	68	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	14	24	31	5.1	22	10
Apr (P13)	3	3.5	8	1.5	36	3
Nov (P14)	7	15	17	3.4	26	6
Avg. Total PPT:						
Jul (P5)	2.7	2.7	3.8	0.3	9.5	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	8.7	--	--	--	--
Jan [(P3/P1).100)]	--	4.8	--	--	--	--
Radiation						
Radiation (R11)(*)	209	211	213	1.0	0.5	216
Evaporation (R10)(in.)	27.5	32	37.5	2.3	7.2	37
Percent Sunshine Jan (R6)	25	35	45	6.3	19.3	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 12

I. PROFILE PLOT

```
MIN.                                                                 MAXIMUM
VALUE               HOMOCLIMES RELATIVE TO EACH OTHER                VALUE

  10 | 12.   .11.18.   | 07.05.04.06.13 | 03.   .15.    .17 | 08.01.   .19.16 |   78
     |  .    .20.   .  |  .   .  .09.   | 10.   .   .    .  |  .   .   .   . |
     |  .    .12.   .  |  .   .  .14.   | 02.   .   .    .  |  .   .   .   . |
     |                                                                       |
     | Highly Similar <------------------------------> Highly Dissimilar     |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	4	8	11	2.1	27	4
Avg. Max. Jul (T11)	75	76	78	1.3	1.6	82
(T11 -T5)	--	68	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	30	35	45	6.1	17	10
Apr (P13)	5	5.7	7.5	1.1	17	3
Nov (P14)	16	21	22	2.5	13	6
Avg. Total PPT:						
Jul (P5)	2.7	2.7	3.3	.19	6.5	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	8.3	--	--	--	--
Jan [(P3/P1).100)]	--	7.6	--	--	--	--
Radiation						
Radiation (R11)(*)	207	209	211	1.4	.7	216
Evaporation (R10)(in.)	28	31	33	1.9	6.0	37
Percent Sunshine Jan (R6)	25	35	35	3.5	10	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 13

I. PROFILE PLOT

```
MIN.                                                                  MAXIMUM
VALUE              HOMOCLIMES RELATIVE TO EACH OTHER                  VALUE

  10 | 13.  .10.  .18 | 09.  .11.  .07 | 14.06.15.  .02 | 17.  .01.19.16 |  106
     |  .   .05.  .20 |  .   .12.  .03 |  .  .  .  .08 |  .  .  .  .    |
     |  .   .12.   .  |  .   .04.   .  | 02.  .  .   .  |  .  .  .  .    |
     | Highly Similar <-----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-8	-6	2	2.9	-55	4
Avg. Max. Jul (T11)	69	78	81	3.8	4.9	82
(T11 -T5)	--	84	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	9	11	13	1.3	12	10
Apr (P13)	2	6	8	1.9	36	3
Nov (P14)	7	8	8	.4	4.9	6
Avg. Total PPT:						
Jul (P5)	2.8	3.5	3.5	0.2	5.9	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	13.5	--	--	--	--
Jan [(P3/P1).100)]	--	3.3	--	--	--	--
Radiation						
Radiation (R11)(*)	202	206	207	1.3	.6	216
Evaporation (R10)(in.)	30	30	30	0	0	37
Percent Sunshine Jan (R6)	45	45	45	0	0	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

HOMOCLIME 14

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	14.06.07.03. . .04.15.	02.17.08. .09 .11. . .18	.01.12. .05 . .20. .08 . .19. .	. .10. .13 . .16.	57

Highly Similar <-----------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	2.5	8	13	2.9	36	4
Avg. Max. Jul (T11)	78	82	85	1.8	2.2	82
(T11 -T5)	--	74	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	7.5	10	23	2.6	23	10
Apr (P13)	1.3	1.9	4	0.8	35	3
Nov (P14)	3	4.5	8	1.1	24	6
Avg. Total PPT:						
Jul (P5)	2.3	3	4	0.4	13.9	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	10.3	--	--	--	--
Jan [(P3/P1).100)]	--	4.5	--	--	--	--
Radiation						
Radiation (R11)(*)	214	218	221	1.4	0.6	216
Evaporation (R10)(in.)	33	37	43	2.7	7.4	37
Percent Sunshine Jan (R6)	25	45	45	8.8	22	4.5

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 15

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	15.08. .14. .03.	17.06.07. .09 04. .02. .19	01. .18. .16 11.	05.10. . .13 20. . . . 12. . . .	64
	Highly Similar <-----------------------------> Highly Dissimilar				

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-6	4	7.5	3.2	84	4
Avg. Max. Jul (T11)	83	85	87	.9	1.1	82
(T11 -T5)	--	81	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	5	7	11	1.3	18	10
Apr (P13)	1.3	2	4	.5	23	3
Nov (P14)	4	5	6.5	.7	13	6
Avg. Total PPT:						
Jul (P5)	2.8	3.5	4	.3	10	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	12.5	--	--	--	--
Jan [(P3/P1).100)]	--	2.9	--	--	--	--
Radiation						
Radiation (R11)(*)	217	219	222	1.6	.7	216
Evaporation (R10)(in.)	38	45	50	2.9	6.4	37
Percent Sunshine Jan (R6)	45	55	55	4.2	8	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 16

I. PROFILE PLOT

```
 MIN.                                                              MAXIMUM
 VALUE             HOMOCLIMES RELATIVE TO EACH OTHER               VALUE

   10 | 16.  .01.  .17 | 02.08.  .06.14 | 07.  .04.11 .12 | 18.20.05.  .10 |   98
      |   .  .19.  .   |   .   .  .15.  | 03.   .   .  .09 |   .   .   .  .13 |
      |   .   .   .   .|   .   .   .   .|   .   .   .   .  |   .   .   .   .  |
      |
      | Highly Similar <------------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	17	17	19	0.7	4.0	4
Avg. Max. Jul (T11)	82	84	85	1.0	1.7	82
(T11 -T5)	--	67	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	13	18	5.3	42	10
Apr (P13)	0.5	1.5	1.5	0.5	43	3
Nov (P14)	2	6	8	2.7	47	6
Avg. Total PPT:						
Jul (P5)	2.8	3.2	4	.30	9.9	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	9.4	--	--	--	--
Jan [(P3/P1).100)]	--	7.1	--	--	--	--
Radiation						
Radiation (R11)(*)	226	227	228	0.8	0.3	216
Evaporation (R10)(in.)	38	40	43	2.1	5.4	37
Percent Sunshine Jan (R6)	35	35	35	0	0	4.5

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 17

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	17. .01.08.06 . .02. .15 . .19. .14	.16.03.04. . .07.	11. .09.18 .12	20.05. .10.13	79
	Highly Similar <------------------------------> Highly Dissimilar				

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	6.5	13	17	2.8	23	4
Avg. Max. Jul (T11)	80	83	87	1.3	1.5	82
(T11 -T5)	--	70	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	8	10	18	1.6	16	10
Apr (P13)	.5	1.5	3	.5	41	3
Nov (P14)	2.5	3.5	7	.9	25	6
Avg. Total PPT:						
Jul (P5)	2.3	3	5	.6	18	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	9.8	--	--	--	--
Jan [(P3/P1).100)]	--	4.8	--	--	--	--
Radiation						
Radiation (R11)(*)	219	222	228	1.5	.6	216
Evaporation (R10)(in.)	33	37	43	2.4	6.1	37
Percent Sunshine Jan (R6)	25	45	45	6.5	17	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 18

I. PROFILE PLOT

MIN. VALUE	HOMOCLIMES RELATIVE TO EACH OTHER				MAXIMUM VALUE
10	18.20.11.09.07	13 .14.03.06.	15.02. .17 .	.01.19. .16	81
	.05. .12.10	. . . .	. . .08 .	. . . .	
	. . .04.14	. . . .	. . . .	. . . .	

Highly Similar <-----------------------------> Highly Dissimilar

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	-1	1	9	1.9	101	4
Avg. Max. Jul (T11)	75	79	87	1.8	2.3	82
(T11 -T5)	--	78	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	7	11	20	2.5	21	10
Apr (P13)	2.9	4.4	7.5	.9	20	3
Nov (P14)	6	8	13	1.7	20	6
Avg. Total PPT:						
Jul (P5)	2.8	4	6	0.6	15	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	13	--	--	--	--
Jan [(P3/P1).100)]	--	3.5	--	--	--	--
Radiation						
Radiation (R11)(*)	208	212	214	1.4	.7	216
Evaporation (R10)(in.)	28	32	38	1.4	4.3	37
Percent Sunshine Jan (R6)	35	40	45	4.9	12.3	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 19

I. PROFILE PLOT

```
 MIN.                                                                MAXIMUM
 VALUE              HOMOCLIMES RELATIVE TO EACH OTHER                VALUE

    10 | 19.01.17.  .08 | 02 .15.14.03.07 | 04.  .11.09 . | 18.20.  .10.13 |   94
       |   .  .16.  .   |  .06.  .  .     |  .  .  .  .   | 12.05.  .  .   |
       |   .  .  .  .   |  .  .  .  .     |  .  .  .  .   |  .  .  .  .    |
       |                                                                   |
       | Highly Similar <-----------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	10	15	20	2.9	19	4
Avg. Max. Jul (T11)	82	83	87	1.4	1.7	82
(T11 -T5)	--	68	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	6	9	13	1.7	18	10
Apr (P13)	0.5	1.2	1.8	0.5	43	3
Nov (P14)	2	3	6	0.9	27	6
Avg. Total PPT:						
Jul (P5)	2.5	3.5	4.5	0.5	15	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	10.7	--	--	--	--
Jan [(P3/P1).100)]	--	4.6	--	--	--	--
Radiation						
Radiation (R11)(*)	223	225	228	1.3	0.6	216
Evaporation (R10)(in.)	33	42	43	2.7	6.7	37
Percent Sunshine Jan (R6)	35	35	45	5	12	45

*Radiation is measured in 1,000's of Langleys, i.e., 223 = 223,000 Langleys

HOMOCLIME 20

I. PROFILE PLOT

```
MIN.                                                        MAXIMUM
VALUE           HOMOCLIMES RELATIVE TO EACH OTHER           VALUE

    |                |                 |                |              |
 10 | 20.18.12.  .   | 13 .10.  .14.   |  .15.  .  .17  | .01.  .19.16 |  85
    |  .  .11.   .   | 07 .  .  .06.   |  .02.  .  .08  |  .  .  .  .  |
    |  .  .05.   .   | 04 .  .  .03.   |  .  .  .  .    |  .  .  .  .  |
    |                | 09
    | Highly Similar <------------------------------> Highly Dissimilar |
```

II. KEY VARIABLE PROFILE

Temperature (°F)	Min	Median	Max	S.D.	C.V.	Region Median
Avg. Min. Jan (T5)	1.5	3	7	1.7	48	4
Avg. Max. Jul (T11)	77	79	81	1.2	1.5	82
(T11 -T5)	--	76	--	--	--	78
Precipitation (in.)						
Avg. Total snowfall:						
Jan (P12)	19	22	34	4.4	18	10
Apr (P13)	5	7.5	10	1.6	22	3
Nov (P14)	17	21	27	2.9	14	6
Avg. Total PPT:						
Jul (P5)	3	3.7	4	.31	8.8	3.2
Percent Total PPT In:						
Jul [(P5/P1).100)]	--	11.5	--	--	--	--
Jan [(P3/P1).100)]	--	4.5	--	--	--	--
Radiation						
Radiation (R11)(*)	210	210	211	0.5	0.2	216
Evaporation (R10)(in.)	33	32	33	0	0	37
Percent Sunshine Jan (R6)	35	35	35	0	0	45

*Radiation is measured in 1,000's of Langleys, i.e.,
223 = 223,000 Langleys

APPENDIX D

Given a system described by N variables, the model upon which principal component analysis is based is given by equation 1.

$$Z_j = A_{j1} \cdot F_1 + A_{j2} \cdot F_2 + \dots A_{jk} \cdot F_k \qquad (1)$$

where:

Z_j = standard score of varible j;
A_{jk} = component coefficient;
F_k = component;
j = 1 to N; and
k = 1 to n.

It is hypothesized in equation 1 that every variable score equals a linear combination of imaginary components. A statistical package program such as SAS 79 (Helwig and Council 1979) can be used to generate a factor pattern matrix (table 4). The factor pattern matrix is equation 1 expanded for every variable Z_j across every component F_k where n, the number of components, is less than N, the number of variables. The elements A_{jk} represent the correlation of variable Z_j with component F_k (table 4).

The next step is to obtain the factor score matrix. The process is best illustrated in matrix notation. Using matrix notation, equation 1 can be written:

$$Z = A \bullet F \qquad (2)$$

where:

Z = vector of variables;
A = matrix of component coefficients; and
F = vector of components.

Solving for F, the following steps for the general case can be used:

$$A' \bullet Z = A' \bullet A \bullet F \qquad (3)$$
$$F = (A' \bullet A)^{-1} \bullet A' \bullet Z$$
$$\text{Let } (A' \bullet A)^{-1} \bullet A' = Q$$
$$\text{then}$$
$$F = Q \bullet Z \qquad (4)$$

Table 4.—*Structure of a factor pattern matrix*

	Component				
Variable	F^1	F^2	F^3	. . .	F^k
Z_1	A_{11} (.83)	A_{12} (.61)	A_{13} (.03)	. . .	A_{1k}
Z_2	A_{21} (.06)	A_{22} (.91)	A_{23} (.55)	. . .	A_{2k}
Z_3	A_{31} (.49)	A_{32} (.03)	A_{33} (.88)	. . .	A_{3k}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
Z_j	A_{j1}	. . .	. . .	. . .	A_{jk}

Note: The A_{jk} members of the factor pattern matrix are correlation coefficients between variables Z_j and components F_k. The numbers in parenthesis are a numerical example. These numbers would come from a computer output of a principal component analysis. In matrix notation the above structure may be written as: Z = A • F.

Table 5.—*Structure of a factor score matrix*

	Variable				
Component	Z_1	Z_2	Z_3	. . .	Z_j
F_1	Q_{11} (1.02)	Q_{12} (– .69)	Q_{13} (.40)	. . .	Q_{1j}
F_2	Q_{21} (.28)	Q_{22} (.93)	Q_{23} (–.59)	. . .	Q_{2j}
F_3	Q_{31} (–.58)	Q_{32} (.36)	Q_{33} (.93)	. . .	Q_{3j}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
F_k	Q_{k1}	. . .	. . .	. . .	Q_{kj}

Note: The numbers in parenthesis are derived from the numbers in table 4. In matrix notation the structure of table 4 can be written as:
Z = A • F. The Q's of this table are derived as follows:
inverse (A) • Z = inverse (A) • A • F
let inverse (A) = Q
Q • Z = F or
F = Q • Z

where:

A′ = transpose of A;
$(A' \bullet A)^{-1}$ = inverse of (A′ • A); and
Q = matrix of component scores.

By expanding equation 4 into algebraic notation, it can be seen that each factor score is a linear combination of all the variables in the system (table 5).

$$F_k = Q_{k1}Z_1 + Q_{k2}Z_2 + \dots + Q_{kj}Z_j \qquad (5)$$

where:

F_k = component scores
Q_k = component scoring coefficients;
Z_j = standard score of variables;
j = 1 to N, the number of variables; and
k = 1 to n, the number of components.

Finally, each observation can be scored across all components (table 6).

The data have now been converted from a matrix of scores for every observation across every variable to a matrix of scores for every observation across a number of components (table 6). In doing this we have reduced the dimensionality of the system without losing a significant amount of information.

Table 6.—*Structure of the matrix of observations scored across all components*

	Component			
Observation	F_1	F_2	F_3	$\ldots F_k$
0_1	X_{11} (0.52)	X_{12} (0.84)	X_{13}(0.64)	$\ldots X_{ik}$
0_2	X_{21} (1.35)	X_{22}(−2.32)	X_{23} (−0.44)	$\ldots X_{2k}$
0_3	X_{31} (−1.42)	X_{32} (−0.44)	X_{33} (1.58)	$\ldots X_{3k}$
.	.	.	.	. .
.	.	.	.	. .
.	.	.	.	. .
0_l	X_{il}	. . .	. . .	$\ldots X_{ik}$

Note: The values for the X's are derived in the following manner. Given the field data in standard scores:

Observation	Z_1	Z_2	Z_3
0_1	1.21	.48	−.96
0_2	.68	−.20	.03
0_3	−.83	−1.20	1.65

$X_{11} = Q_{11} \bullet (Z_1 \text{ of } 0_1) + Q_{12} \bullet (Z_2 \text{ of } 0_1) + Q_{13} \bullet (Z_3 \text{ of } 0_1) = (1.02)(1.21) + (-.69)(.48) + (.40)(-.96) = 0.52$

$X_{23} = Q_{31} \bullet (Z_1 \text{ of } 0_2) + Q_{32} \bullet (Z_2 \text{ of } 0_2) + Q_{33} \bullet (Z_3 \text{ of } 0_2) = (-0.58)(.68) + (0.36)(-0.20) + (0.93)(0.03) = 0.44$, etc.

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Rauscher, H. Michael.

Homogeneous Macroclimatic Zones of the Lake States. Res. Pap. NC-240. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 39 p.

The macroclimate of the Lake States is summarized and described by mapped homoclimatic zones. Cluster analysis in conjunction with principal components analysis were used to derive the homoclimatic zones. Each homoclimatic zone is qualitatively and quantitatively compared to all the others.

KEY WORDS: Classification, cluster analysis, principal components analysis.

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Forest Service

North Central Forest Experiment Station

Research Paper **NC-241**

Pre-plant Soaking of Dormant *Populus* Hardwood Cuttings

Howard M. Phipps, Edward A. Hansen, and Anne S. Fege

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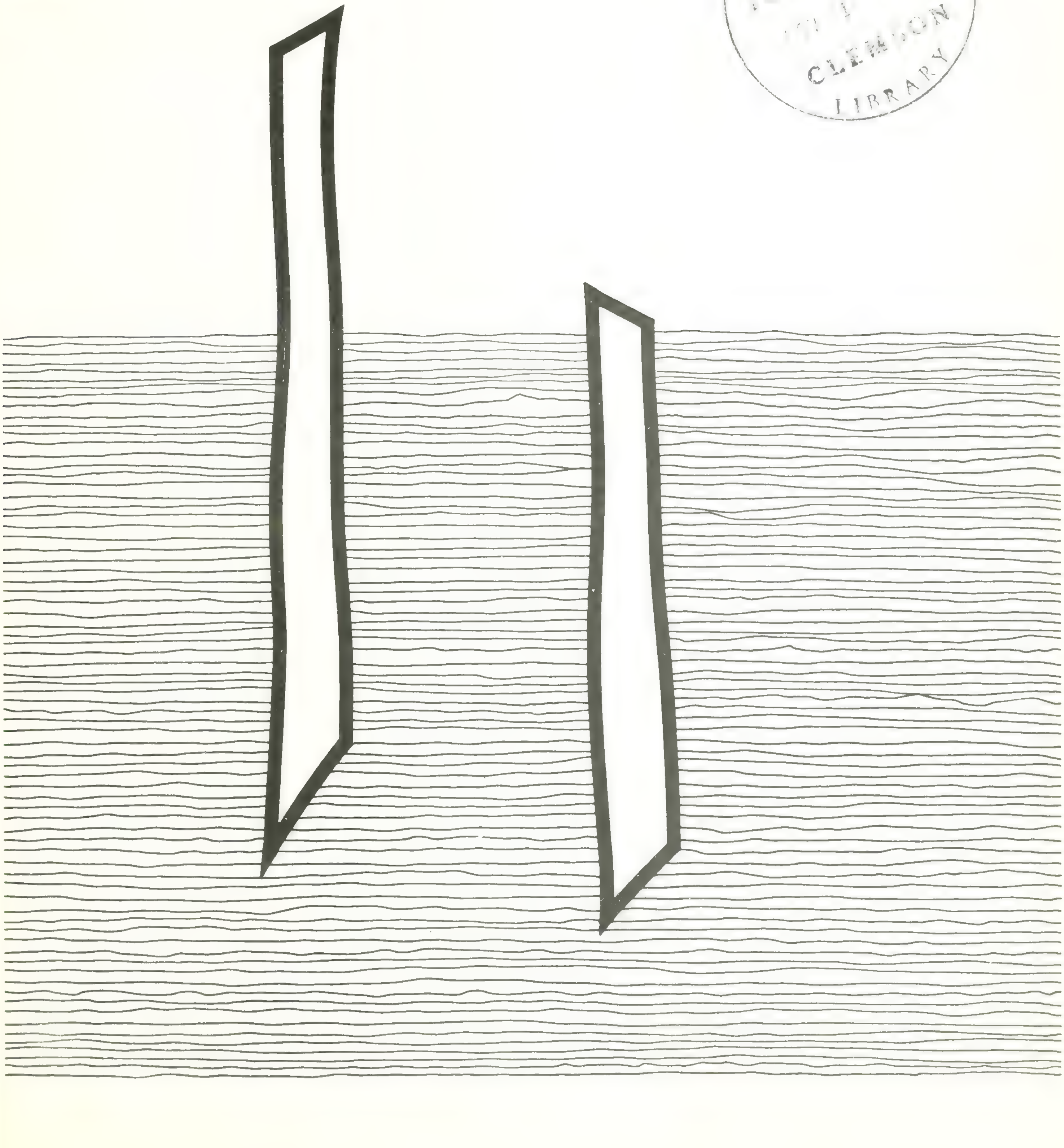

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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PREPLANT SOAKING OF DORMANT *POPULUS* HARDWOOD CUTTINGS

Howard M. Phipps, *Research Forester,*
Edward A. Hansen, *Principal Hydrologist,*
Rhinelander, Wisconsin,
and **Anne S. Fege,** *Graduate Assistant,*
University of Minnesota,
St. Paul, Minnesota

Most *Populus* species and hybrids of the Aigeiros and Tacamahaca sections e.g., black poplars, cottonwoods, and balsam poplarsare readily propagated from dormant hardwood cuttings. Cuttings provide a convenient means of establishing fast growing, short rotation plantations for producing fiber or energy. As a standard procedure we harvest 1-year-old coppice shoots from a cutting orchard in December or January and cut them into 20 cm lengths. Cuttings with a diameter from 9 to 12 mm are selected and stored in sealed plastic bags at a temperature a few degrees below freezing. In the spring, cuttings are planted about 15 cm deep. However, early survival and growth of such plantations will depend largely on cutting vigor and weather conditions at planting time. One treatment that has been shown to increase early cutting survival and growth—especially during hot, dry periods—is to soak the cuttings before planting.

In a study with several *Populus* clones Bloomberg (1963) found that increased cutting moisture content significantly increased the number, length, and weight of initial roots of cuttings, and he also demonstrated the importance of these roots to subsequent survival and growth. Petersen and Phipps (1976) compared field survival of cuttings soaked in water with unsoaked cuttings of three different *Populus* clones and found soaking increased the rate of leaf flushing and survival of all clones. Similar benefits of water soaking to the field performance of *Populus* cuttings were found by dePhilippis (1966) in Italy and by Edwards and Kissock (1975) with both *Populus* and *Salix* clones in New Zealand.

To further evaluate water soaking and other preplanting treatments, we investigated such variables as water temperature, length of soaking time, depth of cutting immersion, and effects of soaking in relation to time of planting and soil moisture. This paper reports the results of a number of interrelated studies designed to improve our knowledge and develop techniques for preplant handling of hardwood cuttings. Use of these techniques should improve early survival and growth of new plantations.

EFFECT OF SOAKING DURATION

Several tests were performed in a growth room to determine how long cuttings must be soaked in water to gain the best subsequent root and shoot growth. As part of a study to determine the effects of moisture stress on hardwood cutting performance, we compared the effects of soaking for different lengths of time on the earliness of bud flush and the rate of shoot growth. We used 20-cm-long cuttings from the following clones: NC-9922, NC-5260, and NE-387 (NC-5262) (see table 1 for parentages). The cuttings were given the following treatments: (1) no pretreatment (cuttings were taken directly from cold storage at 2°C and planted); (2) cuttings were "warmed" at 3°C for 2 weeks and then soaked in the dark in water at 16°C for 4 days, and (3) cuttings were warmed and soaked as in treatment 2 except soaking duration was 10 days at which time the roots were about to emerge. In this study, as well as the studies described below, cuttings were soaked in the dark to avoid possible inhibition of root growth by light.

Two replications of all clone x soaking treatment combinations (54 cuttings total) were placed in a randomized block design in each of 12 boxes; each box having a different soil moisture tension ranging

Table 1.—*Clone numbers and parentage of* Populus *hybrids used in preplant treatment studies*

Clone no.		
Original Northeast	**North Central**	**Percentage**
NE-386	NC-5263	*Populus* cv. *Candicans* X (*P.* X *berolinensis*)
NE-387	NC-5262	*Populus* cv. *Candicans* X (*P.* X *berolinensis*)
NE-252	NC-5334	*Populus deltoides* var. *angulata* X *P. trichocarpa*
—	NC-5377	*Populus* X *euramericana* cv. Wisconsin #5
—	NC-9922	*Populus* spp. (Very similar to NE-252)
—	NC-5260	*Populus tristis* X *P. balsamifera* cv. Tristis #1

from 0 to -0.6 bars. The cuttings were all planted on the same day. Shoot length was measured at 10, 14, and 18 days after planting. For analyzing the effects of the soaking period duration, all soil moisture treatments were pooled.

The soaking treatments had a major effect (p = 0.05) on the rapidity of flushing and consequently on shoot length (fig. 1). In almost all cases, the no-soaking treatment was the poorest and the 10-day soak the best in terms of percent flushing and shoot length at either 10 or 18 days. At the 10-day measurement, from 45 to 98 percent of the cuttings in the 10-day soaking treatment had flushed depending upon clone; the 4-day soak was intermediate; and none of the unsoaked cuttings had flushed. By 18 days the percentage of flushed cuttings of the 4-day soak was almost equal to that of the 10-day soak. However, the shoot length of the flushed 4-day soaked cuttings was still much less than that of the 10-day soak. Shoot length increased with soaking duration because of earlier flushing. Once the cuttings flushed, growth rate was similar as evidenced by the nearly constant difference in shoot length between the 4- and 10-day soaking treatments measured at 10 days and 18 days.

Evidence of the importance of soaking was also obtained in another growth room test in which response was measured in terms of average shoot length, number of roots, length of longest root, and total root dry weight. In all cases, cuttings that were not soaked showed the least growth of both roots and shoots. For those treatments that involved soaking, results differed to a large extent by clone. For example, 14 days after planting, root length and root dry weight of clone NE-252 (NC-5334) increased significantly with increased soaking duration up to 11 days (the point of root emergence). However, only root length of clone NC-5377 increased significantly during the same period. Although average shoot length of both clones increased with soaking duration, statistical significance could not be shown.

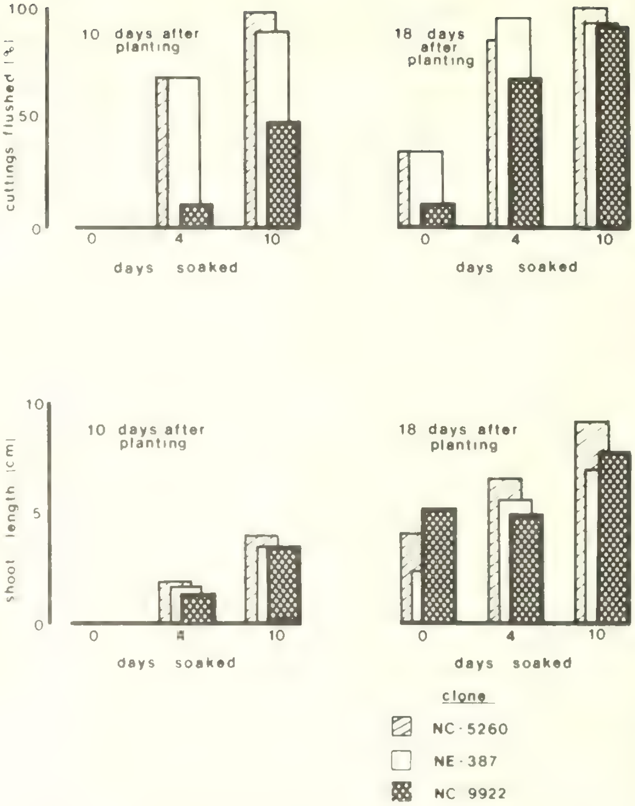

Figure 1.—*Relation of early bud flushing and shoot length to soaking pretreatments at 10 and 18 days after planting. Data from soil moisture tension treatments were pooled for each soaking treatment.*

On the average, soaking cuttings to the point of root emergence (from 9 to 11 days in 16°C water) was most effective for stimulating root and shoot development. Significant response differences to soaking duration due to clone have also been reported by other investigators (dePhilippis 1966; Edwards and Kissock 1975). Because the optimum soaking duration may differ by clone, soaking to the point of root emergence would be the most practical method when dealing with unfamiliar clones (fig. 2).

EFFECTS OF SOAKING DEPTH

How deeply cuttings must be immersed in water or whether immersion is actually necessary to obtain maximum water uptake and to stimulate rooting was investigated in two studies. In the first study,

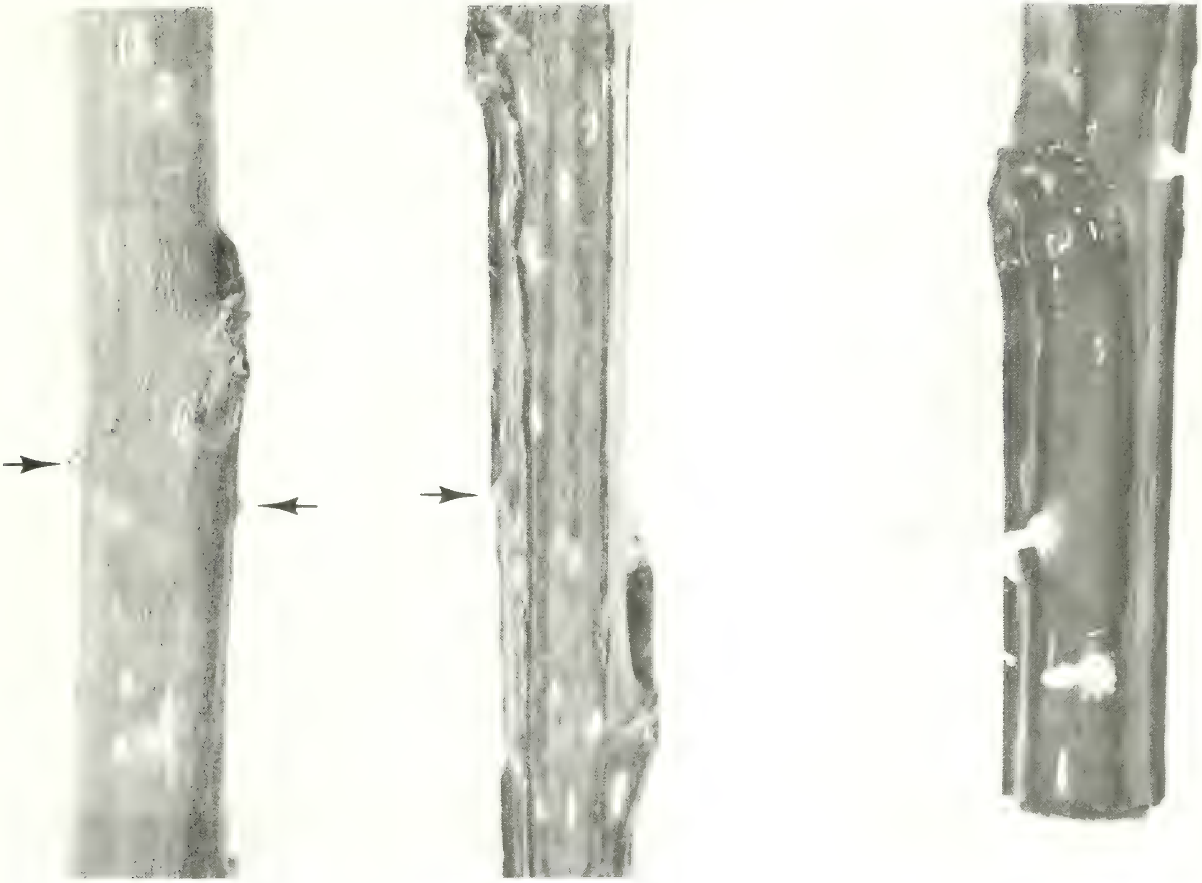

Figure 2.—Populus *hardwood cuttings soaked to the proper stage for planting (left and center) with swellings of roots about to emerge as indicated by the arrows. On the right a cutting soaked too long with roots already emerged.*

20-cm-long cuttings of clone NC-9922 were treated as follows: (1) entire cuttings exposed to a moisture-saturated atmosphere in a sealed plastic bag; (2) bases soaked to 3 cm depth in a saturated atmosphere; (3) bases soaked to 15 cm depth; and (4) bases soaked to 15 cm depth in aerated water. The last two treatments were applied in open containers and therefore not in a saturated atmosphere. Responses measured were number of days until roots emerged and weight gain at the time of root emergence. No significant differences were found in percent weight gain due to treatment (shown below) except for the cuttings in the saturated atmosphere treatment which absorbed significantly less ($p = 0.05$) water. Percent weight gain was used because within any treatment weight gain was proportional to initial cutting weight (size). Roots emerged at about 15 days in all treatments except the aerated 15 cm soak treatment where rooting began after about 24 days.

Treatment	Percent weight gain
1. Moist atmosphere	10
2. 3 cm soak	19
3. 15 cm soak	19
4. 15 cm soak with aeration	29

In a second test, 20-cm-long cuttings of clones NE-252 (NC-5334), NE-387 (NC-5262), and NC-5377 were soaked to depths of 3 cm and 15 cm for 9 days to determine effects on shoot length, root length (as measured by the two longest roots per cutting), and total dry weight of roots. Results showed no effect of soaking depth on shoot length. Root length and root dry weight were greater for the deeper soaking treatment (5 percent and 24 percent, respectively), but statistical significance ($p = 0.05$) was found for only one clone, NC-5377.

These tests show that soaking of 20-cm-long cuttings in 15 cm of water may slightly benefit root growth of certain clones compared to a shallow soaking of 3 cm. With other clones no benefit to growth was indicated by the deeper soaking treatment. Although some uptake will occur by merely exposing the cuttings to a moisture-saturated atmosphere, significantly more moisture will be absorbed when the bases of the cuttings are immersed.

WATER UPTAKE IN RELATION TO WATER TEMPERATURE

To find out if temperature might be an important factor in water uptake, we soaked cuttings of clones NE-386 (NC-5263) and NE-252 (NC-5334) in water at 4.4°C and 15.6°C in the dark for 14 days. Ten, 20 cm long cuttings of each clone were weighed before soaking in 15 cm of water and again each subsequent day to calculate average percent weight gains. The curves representing these gains revealed a more rapid and sustained weight increase at the higher temperature for both clones (fig. 3). Weight was still increasing substantially at the end of the test for the 15.6°C treatment, whereas uptake rate for the 4.4°C treatment plateaued at about 9 days and increased only slightly thereafter.

Root initials began to develop, as indicated by the formation of bark swelling or bumps, and buds began to break in the 15.6°C treatment about 8 days after soaking started. Even after 14 days no evidence of the initiation of growth was seen in the 4.4°C treatment.

These results suggest that a soaking temperature of 15.6°C would be superior to 4.4°C for several reasons. The higher moisture content may favor the production of a more vigorous initial root system, and initiation of root and shoot growth are accelerated thus reducing the soaking duration. Extended periods of soaking, especially if the water should stagnate, can be detrimental to subsequent growth (Edwards and Kissock 1975).

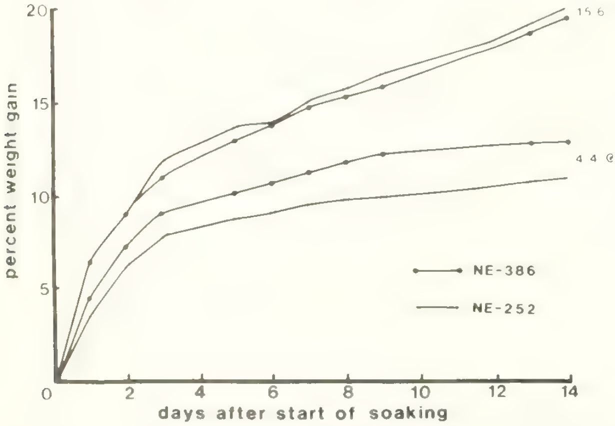

Figure 3.—*Percent weight gain of hardwood cuttings of two* Populus *clones in response to two water soaking temperatures.*

THE PROBLEM OF DELAYS IN PLANTING SOAKED CUTTINGS

When soaked cuttings have reached the proper stage for planting, as indicated by visible swelling of root initials and leaf buds, roots and shoots extend very rapidly. Therefore, cuttings at this stage should be planted within a day or two so that initial roots and developing leaves will not be damaged either mechanically or by exposure to heat and drying during transport and planting. Also, at this stage of root development respiration rates will increase rapidly and if the cuttings are not promptly planted, much of the stored food reserves on which cuttings depend for their initial growth will be depleted. If planting must be delayed or interrupted for more than a few days, the field manager will be confronted with the problem of how best to maintain the vigor of the cuttings until they can be planted.

To determine if soaked cuttings could be stored satisfactorily for a short period of time, we studied the effects of storing hardwood cuttings (soaked to the point of root emergence) of clones NE-386 (NC-5263) and NE-252 (NC-5334) in crushed ice in styrofoam boxes for 2 weeks. The effects of air drying soaked cuttings for 8 hours at about 24°C were also studied, with and without subsequent 2 week storage on ice before planting. The drying treatment was chosen to simulate a harsh condition that might occur during a field planting operation. These treatments were superimposed on cuttings soaked for various lengths of time in water at 4.4°C and 16°C. After treatment, cuttings were potted, grown for 4 weeks in a growth room, and responses measured in terms of number of shoots and length of the longest shoot and longest root.

Neither shoot number nor shoot length of either clone was significantly reduced by either cold storage or drying alone. However, drying followed by cold storage reduced average root length by approximately 15 mm (fig. 4). Other significant differences found in this study were: clonal differences in the number of shootsgrowth of clone NE-386 (NC-5263) was consistently greater than that of clone NE-252 (NC-5334)and growth of shoots and roots was greater for the 16°C soaking temperature. These results indicate that exposing soaked cuttings to both drying and cold storage may cause a slight, early loss of root

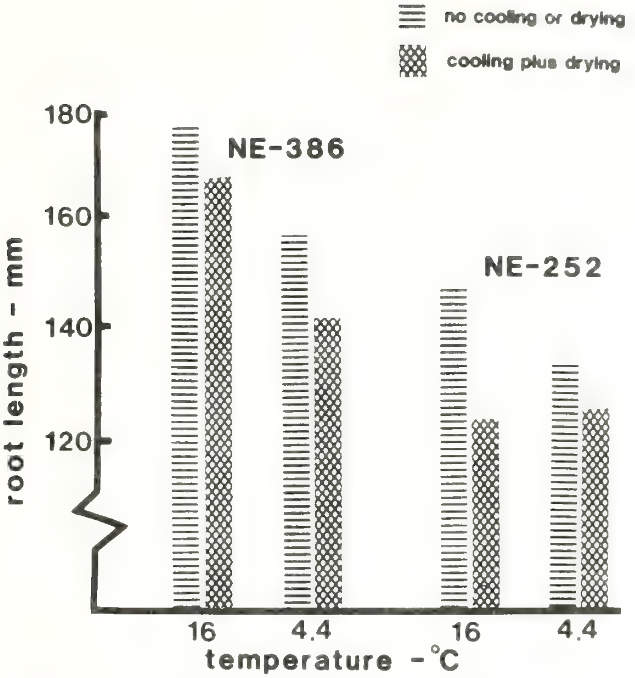

Figure 4.—*Effect of cooling plus drying treatments on root length of two Populus clones 4 weeks after planting. Cuttings were soaked at either 16°C or 4.4°C for 10 days before planting.*

growth. Whether the effects of this loss would persist after field planting and significantly reduce biomass is not known. However, in view of the otherwise normal survival and top growth development it is likely that adverse effects would be negligible for short periods of drying and up to 2 weeks storing on ice. Thus, it appears that up to 8 hours drying can be tolerated (though it should be avoided if at all possible) and that storing soaked cuttings on ice for as long as 2 weeks will maintain the vigor of soaked cuttings when unavoidable planting delays or interruptions are experienced.

SOAKING EFFECTS AS RELATED TO SOIL MOISTURE

The advantages of soaking *Populus* hardwood cuttings were observed in a field planting made during a year with an exceptionally hot, dry spring. Unsoaked cuttings showed very slow bud break and poor rooting in contrast to soaked cuttings, which developed and grew with normal vigor. Measurements of soil moisture tension during this period showed a range of -0.2 to -0.4 bars, which ordinarily indicates adequate moisture for satisfactory cutting development. We speculated that the hot, dry atmospheric conditions during the time of planting depleted cutting moisture reserves before their root systems could develop and replace the moisture loss.

To more closely define the relation between soil moisture status and rate of flushing and shoot growth, we studied the effects of various soil moisture tensions on the development of soaked cuttings.

Part of the methodology for this study has been described in the section on "Effect of Soaking Duration". Additional details are as follows. Twelve boxes were lined with aluminum foil and plastic to prevent moisture or gas movement through the sides or bottom of the boxes. Soil at different moisture tensions (achieved by mixing different quantities of water with each soil batch) was then placed in the boxes and covered with polyethylene to prevent moisture loss but yet permit gas exchange. The goal was to have the soil moisture tensions equally distributed between 0 and -0.6 bars. Soil moisture tension was monitored with a soil moisture block in the two driest treatments and with a tensiometer centrally located in each box in the other treatments. Growth room conditions were 15 hours of daylight, day-night temperatures of 27°C and 16°C, respectively, and soil temperature fluctuating diurnally between 30°C and 20°C. Although we used three clones in this study, the experimental results were similar for all clones and therefore we will present the data for only one clone (NC-5260).

The soaking treatments accelerated bud flushing over the entire range of soil moisture tensions investigated. The advantage of soaking on flushing is particularly evident at the drier (-0.5 bar) soil moisture tension where none of the unsoaked cuttings but all of the 10-day soaked cuttings had flushed 18 days after planting (table 2). Also, almost all of the 10-day soaked cuttings had flushed by just 10 days after planting. In contrast, none of the unsoaked cuttings flushed by 10 days after planting.

The accelerated flushing from soaking resulted in increased shoot length at all soil moisture tensions (fig. 5). Shoot length measured 10 days after planting averaged about 2 cm longer (about twice as long) for 10-day as compared to 4-day soaked cuttings. This

Table 2.—*Effect of soaking cuttings on percent flushing over a range of soil moisture tensions*
(In percent flushed)

Soaking treatment	10-day results tension (– bars)			18-day results tension (– bars)		
	0.1	0.3	0.5	0.1	0.3	0.5
Unsoaked	0	0	0	66	17	0
4-day	92	58	25	100	92	58
10-day	100	100	92	100	100	100

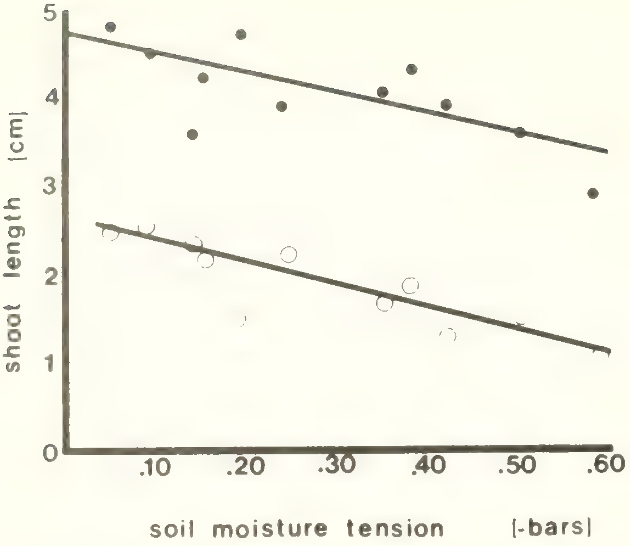

Figure 5.—*Relation of shoot length at 10 days to soil moisture tension for soaking treatments of clone NC-5260. The treatments consisted of soaking 10 days (●), and 4 days (○). The unsoaked cuttings had not yet flushed.*

increase in shoot length was constant for the range of soil moisture tensions examined. The regressions of shoot length against soil moisture tension were linear and significant. The effects of the soaking treatments were significantly different from each other and from the unsoaked treatment.

Thus, soaking accelerated flushing which in turn increased early growth under all soil moisture conditions. Perhaps most importantly, soaking may make the difference between success or failure of the cuttings under drier (-0.5 bar) soil moisture conditions.

SOAKING IN RELATION TO PLANTING DATE

Because it is possible that soaking may be more effective at certain times during the planting season than at others, we studied the effects of soaking on survival and height growth of cuttings planted at various dates during the season. Soaked and unsoaked cuttings of clones NC-5260 and NC-9922 were planted every 2 weeks beginning just after snowmelt and continuing throughout the summer. Half the cuttings of each clone were soaked at a 15 cm depth for 5 days prior to planting. Five cuttings of each treatment were planted at randomly selected locations in each of eight replications of which four were irrigated and four unirrigated. Tree height and survival were measured at the end of the first growing season.

Due to the wet season and good weed control, irrigation had no significant effect on survival or height growth so we pooled the data from the irrigated and unirrigated plots for analysis of soaking effects. Soaking generally increased height growth regardless of the planting date (fig. 6). Only the May 7 planting date showed no soaking benefit and the late August planting dates showed mixed benefits by clone from soaking. Because height growth did not differ significantly with planting date during the first four planting dates, those dates were pooled for analysis of variance to determine soaking effects. The results showed that soaking significantly increased height growth of both clones by 9.8 cm (about 13 percent). Mean tree heights for the first four planting dates of both clones pooled along with their standard errors are shown below.

Treatment	Tree height (cm)	Standard error
Soaked	86.22	1.26
Unsoaked	76.47	1.25

Soaking also resulted in increased height growth for the June 18 and the July 16 planting dates. Later dates showed mixed benefits from soaking. Soaked cuttings planted at those later dates were more susceptible to damage from late summer frosts than unsoaked cuttings. In general, the growth lost from freeze-back was about the same as the growth gained from soaking.

In conclusion, it appears that soaking cuttings increases tree height throughout the normal spring-early summer planting period. Because these results were obtained under wet field conditions, soaking benefits could be even more pronounced during dry conditions.

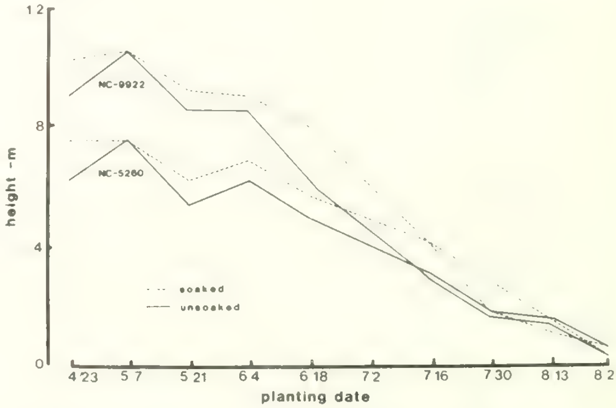

Figure 6.—*Effect of soaking cuttings on first season height growth as related to planting date for two clones.*

THE PROBLEM OF DELAYED DEVELOPMENT OF CUTTINGS STORED AT SUBFREEZING TEMPERATURES

Populus hardwood cuttings usually store well for 2 to 3 months at a temperature of about 3°C. For longer periods, it is advisable to store them at subfreezing temperatures to prevent premature sprouting and deterioration. However, storing cuttings at -17.8°C or -3.9°C for 5 months significantly delayed both shoot and root development compared to storing at 3°C (Phipps and Netzer 1981). Although the cause of this phenomenon is not known, it is probably associated with the activity of enzymes and hormones necessary to resume growth and mobilize food reserves. Because field establishment success will largely depend on how rapidly root systems develop, it was important to find a solution to the problem of delayed root and shoot development. Therefore, we investigated the possibility of overcoming this growth inhibition by transferring cuttings that had been in subfreezing storage to a temperature of 3°C ("warming") for various periods of time before soaking. Variables also studied in this series of tests were length of the soaking period and depth of soaking as covered in previous sections. In a preliminary test, cuttings of four clones were "warmed" for 0, 2, or 4 weeks and then soaked in 15 cm of water for either 0, 1, or 3 days, or until roots began to emerge. Cuttings were then potted and grown for 3 weeks in a growth room. Growth responses measured were: average shoot length, average number of roots, and average length of the three longest roots per cutting. Most of the cuttings that were neither "warmed" nor soaked failed to develop shoots or roots by the end of the test, so this treatment was eliminated from further testing. Although soaking was partially effective in overcoming the inhibitory effects of storage, "warming" for 2 weeks before soaking was clearly the most favorable treatment (table 3). "Warming" for 4 weeks showed no additional benefit over "warming" for 2 weeks.

Table 3.—*Effects of "warming" cuttings before soaking on root development. Data are averages of 1 day, 3 day, and "to root emergence" soaking treatments as measured 3 weeks after planting*

"Warming" (wks)	Shoot length	Roots	Root length
	Cm	*No.*	*Cm*
0	18	16	12
2	24	19	16

To further define the most favorable "warming" procedure, we selected 20-cm-long cuttings of clones NE-387 (NC-5262), NE-252 (NC-5334), and NC-5377 that had been stored for 1 year at -7°C and transferred them to a storage temperature of 3°C for either 1 or 2 weeks. Then we soaked the cuttings in either 3 cm or 15 cm of water for 3, 7, or 11 days at 16°C. After soaking, cuttings were planted 15 cm deep in boxes filled with sand and placed in a growth room with an 18 hour photoperiod and 25°/18°C day-night temperatures. Cuttings were watered daily and given a complete nutrient solution weekly. Growth responses measured 14 days after planting were: length of longest shoot, number of roots, and total weight of roots.

"Warming" for 2 weeks generally produced a greater number and weight of roots and longer shoots than did "warming" for 1 week (table 4). Survival was complete in all treatments. Because of the incomplete factorial design of the study, not all 3 and 11 day soaking and warming treatment combinations were included. Therefore, the 7 day soaking treatment was selected to best illustrate the differences between the two warming treatments. To compare specific treatments we analyzed treatment combinations that made up a complete factorial. For example, length of warming period was analyzed by comparing three pairs of treatments with the same length and depth of soaking and either 1 or 2 weeks of warming. This analysis showed that length of warming significantly affected all measurements ($p = 0.01$) with clone x length of warming treatment interaction significant for number of roots ($p = 0.05$). The effects of soaking depth were consistent with the effects described in the previous section "Effect of Soaking Depth".

Table 4.—*Growth response of three hybrid poplar clones stored at −7°C for 1 year, "warmed" for 1 or 2 weeks at 3°C, soaked for 7 days in 15 cm of water, and then grown for 2 weeks in a growth room*

	Clone					
	NE-387 (NC-5262)		NE-252 (NC-5334)		NC-5377	
	warmed		warmed		warmed	
Growth measurement	1 wk	2 wk	1 wk	2 wk	1 wk	2 wk
Roots (no.)	22	26	33	33	21	25
Roots weight (mg)	0.07	0.10	0.18	0.22	0.10	0.13
Longest shoot length (mm)	79	111	83	95	71	71

The differences between the treatment effects were not large for some clones and variables. However, it is likely that most of these warming and soaking treatments will improve rooting of cuttings in the field. All of the treatments produced a mean of at least 15 roots per cutting and primary shoots of 6.0 cm within 2 weeks in a growth chamber. It appears that a "warming" period of about 2 weeks at 3°C followed by soaking to the point of root emergence will bring cuttings that have been stored at subfreezing temperatures to the proper physiological condition for good postplanting development.

SUMMARY

To define soaking procedures that would most benefit cutting establishment and growth, we investigated the influence of such factors as length of soaking period, depth of soaking, and water temperature. We also studied the problem of maintaining soaked cuttings during planting delays and that of slow development of cuttings stored at subfreezing temperatures.

Although treatment effects in many studies were significantly influenced by clone, a soaking prescription was developed that is generally beneficial for all the clones in our studies. To overcome the problem of slow development of cuttings stored at subfreezing temperatures, "warming" by raising the storage temperature to 3°C for 1 or 2 weeks before soaking enables the cuttings to grow at a normal rate. Soaking in the dark to the point of root emergence in water at 16°C consistently accelerates growth. Some clones respond equally well to a soaking depth of either 3 cm or 15 cm, but other clones benefit more from the deeper soaking. Therefore, the latter treatment is recommended, especially for unfamiliar clones. Soaked cuttings ready for planting can be stored on ice for as long as 2 weeks with little loss of subsequent growth. Although root growth was reduced slightly, overall development of cuttings stored on ice was essentially equal to that of unstored cuttings. Air drying soaked cuttings for 8 hours also had negligible adverse effects.

In field studies we found that water soaking improves survival and growth of cuttings over a wide range of soil moisture conditions. In particular, water soaking is beneficial under hot, dry conditions that induce high moisture stress. Even under ideal weather and site conditions soaking may increase shoot growth. Soaking cuttings for 10 days in effect extends the field growing season by 10 days. This is the equivalent of a 10 percent extension of a 100 day field growing season; we measured a 13 percent first year growth gain for our approximate 90 day growing season even under irrigated field conditions. Benefits from soaking *Populus* hardwood cuttings may not always be realized to the same degree as found in studies described above because of the major influences exerted by local environmental conditions. However, at the least, soaking will help to ensure successful plantation establishment and growth under a variety of site and weather conditions.

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Summarizes results of a series of growth room and field studies to develop and evaluate water soaking procedures for improving the establishment of *Populus* hybrid hardwood cuttings.

KEY WORDS: Vegetative propagation, hybrid poplar, plantation establishment, artificial regeneration

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Weight and Volume Equations and Tables for Red Maple in the Lake States

T. R. Crow and G. G. Erdmann

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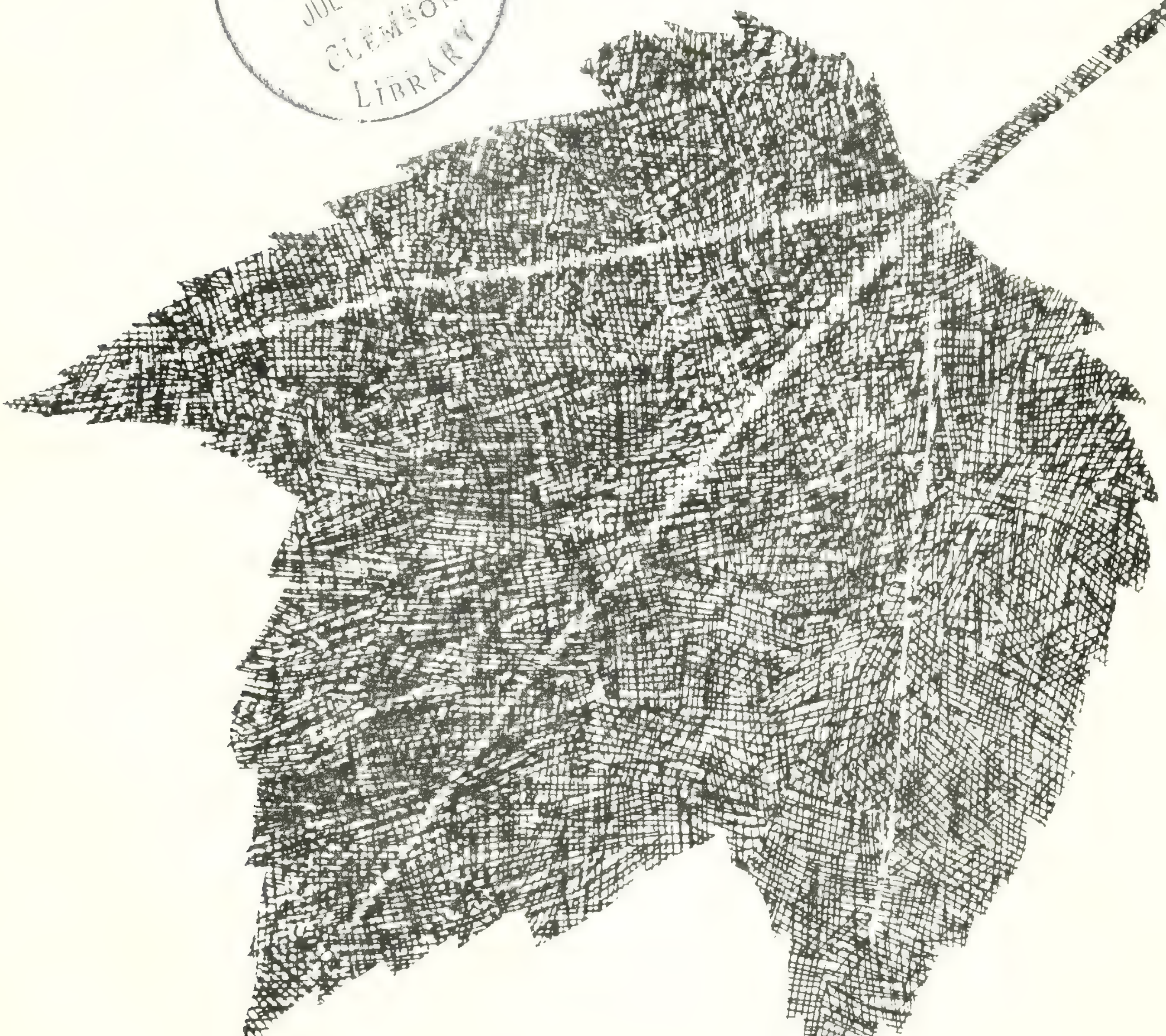

Crow, T. R.; Erdmann, G. G.
Weight and volume equations and tables for red maple in the Lake States. Res. Pap. NC-242. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 14 p.

Weight and volume information based on regional sampling are provided for red maple in the Lake States. Both green weight and dry weight values are presented for biomass. Volume equations predict total stem volume, volume to 8-inch top, and volume to 4-inch top, inside and outside bark.

KEY WORDS: *Acer rubrum,* biomass, total tree weight, component weight, stand weight, stem volume.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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WEIGHT AND VOLUME EQUATIONS AND TABLES FOR RED MAPLE IN THE LAKE STATES

T. R. Crow, *Research Ecologist,*
Rhinelander, Wisconsin,
and **G. G. Erdmann,** *Silviculturist*
Marquette, Michigan

Red maple (*Acer rubrum* L.) is a common component of second-growth forests in the Lake States. In Michigan's Upper Peninsula, it is second only to sugar maple (*Acer saccharum* L.) in terms of standing volume, and it is an important resource on more than 1 million acres of commercial forest in the region.

Changing patterns of utilization have resulted in the need for mensurational information expressed as weight or biomass (Young 1974). In addition, more traditional mensurational units such as volume need to be derived for various standards of utilization. Although regression equations are available for predicting biomass of many hardwood species including red maple, most of these predictive equations are based on limited sample numbers and sample sites. Nothing in the theory of regression analysis suggests that these equations can be applied elsewhere—they are valid for regional application only if they are based on regional sampling.

As part of a program in growth and yield research in northern hardwoods, volume and biomass information are presented here for red maple. The study objective was to predict weight and volume for red maple stands and individual trees across a range of stand ages and site qualities. The scope of the research included:

(1) developing regression estimators for whole-tree and component weights and volumes for red maple and comparing these estimators among sites;

(2) preparing weight tables from regression equations for the total tree and its components by d.b.h. and total height classes; and

(3) predicting stand weights from measurements such as basal area and mean stand height.

METHODS

To provide a regional framework for predicting red maple weight and volume, sample sites were selected in Michigan and Wisconsin that represented the population of even-aged hardwood forests in the Lake States. Six sample stands, each dominated by red maple, were selected as closely as possible to the following age and site index (at age 50) specifications:

Stand age (years)	**Site index** (SI)
40	≤45
70	≤45
40	50–55
70	50–55
40	≥60
70	≥60

Sugar maple was a common associate of red maple on all sites. In the 70-year-old stands, beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), basswood (*Tilia americana* L.), and hemlock (*Tsuga canadensis* (L.) Carr) were also common components. Other species frequent to the 40-year-old stands include black cherry (*Prunus serotina* Ehrh.), pin cherry (*Prunus pensylvanica* L.), paper birch (*Betula papyrifera* Marsh.), and aspen (*Populus tremuloides* Michx).

Within a sample stand, all red maple were numbered and d.b.h. measured and recorded. The numbered trees were partitioned into five d.b.h. classes (minimum diameter = 10 cm d.b.h.), with each class having an equal number of stems. Within a class, five trees were randomly selected for destructive sampling, thus providing 25 trees per site for a total of 150 samples in the study (table 1.)

The procedures used to sample biomass of individual trees have been presented elsewhere (Crow 1983). Total tree in our paper refers to aboveground weight and is the sum of live canopy, dead branches, bole, and stump. Total canopy includes live branches and leaves but excludes dead branches.

Weight/tree dimension relations were expressed in the linear form of the allometric equation:$\ln Y = a + b(\ln X) + \ln \epsilon$. D.b.h. and D^2H (D.b.h. squared times total height) were the independent variables; green weight and dry weight were the dependent variables. Both English and metric units are provided. Analysis of covariance was used to determine if significant differences existed among sets of allometric equations representing the six sites (Snedecor and Cochran 1967).

Standardized curves were also developed for each stand age (40 and 70 years) using dummy variables in a multiple regression to control spacing (Jacobs and Cunia 1980, Draper and Smith 1981).

By fitting
$\ln Y = \ln B_0 + B_1 \ln X + \alpha_1 \ln Z_1 + \alpha_2 \ln Z_2 + \ln \epsilon$,
where $(\ln Z_1, \ln Z_2) = (1,0)$ for $SI \leq 45$
$(\ln Z_1, \ln Z_2) = (0,1)$ for SI 50-55
$(\ln Z_1, \ln Z_2) = (0,0)$ for $SI \geq 60$

and substituting for the three sets of values for $\ln Z_1$ and $\ln Z_2$, three curves with the same slope but different intercepts are obtained. Uniform spacing among intercepts is obtained by regressing the intercept with site index and using the estimated intercepts in the standardized curves.

A set of asymptotic regressions is also calculated using the model, $Y = \alpha + B_P^Z$,
where: Y is the dependent variable that approaches an asymptotic limit as Z approaches infinity;
α represents the asymptotic values of Y;
B represents the total change in Y as Z passes from 0 to +;
P represents the factor by which the rate of change in Y reduces as Y approaches its asymptote; and
Z is the independent variable.

Schwandt's (1979) procedures for estimating the vector parameters for asymptotic regression were used to simultaneously fit the curves.

For volume predictors, two additional sampling locations were added to the six sites previously mentioned. The additional sites, both located in Michigan, included a SI = 61, 50-year-old stand and a SI = 63, 53-year-old stand. Volumes were predicted using the linear form of the allometric equation and a simple linear model with D.B.H., D.B.H.^{2}, and D^2H as the independent variables.

APPLICATION OF EQUATIONS

Differences in stand age and site index did not result in significant differences in biomass or volume equations. Regardless of the independent or dependent variable tested, no statistical differences were found at the $P \leq 0.05$ level in regression slopes or intercepts among the sample sites (Crow 1983).

These results indicate that a general biomass predictor is valid for red maple within the range of data tested (table 1). Because the sample sites represent the range of site and stand conditions for red maple in the Lake States, the general predictors are recommended for regional inventories within the Lake States (table 2). Application of a general predictor to a specific site or application outside the sample region, however, could result in substantial bias.

The error associated with weight estimates did differ substantially among components (table 2). Total tree weight or bole weight can be estimated with greater confidence than canopy weight.

Although differences among the D^2H predictors were statistically nonsignificant using the test criterion $P \leq 0.05$, plots of individual curves often indicated consistent trends among equations that were correlated to site index and stand age (fig. 1). This consistency suggests that for specific sites, greater accuracy can be obtained by including site quality and stand age in the predictive model. Under the assumption that a larger sample size would result in uniform spacing among curves in figure 1, the original equations for total weight/D^2H have been "standardized" using dummy variables to control spacing. When applying these predictors, simply select a table based on the weight units (English or metric, green weight or dry weight) and select the predictor that most closely represents your sample population in terms of stand age and site quality. Total tree weights are given in the following tables:
Table 3—green weight-metric, stand age~40 years,
Table 4—green weight-metric, stand age~70 years,
Table 5—dry weight-metric, stand age~40 years,

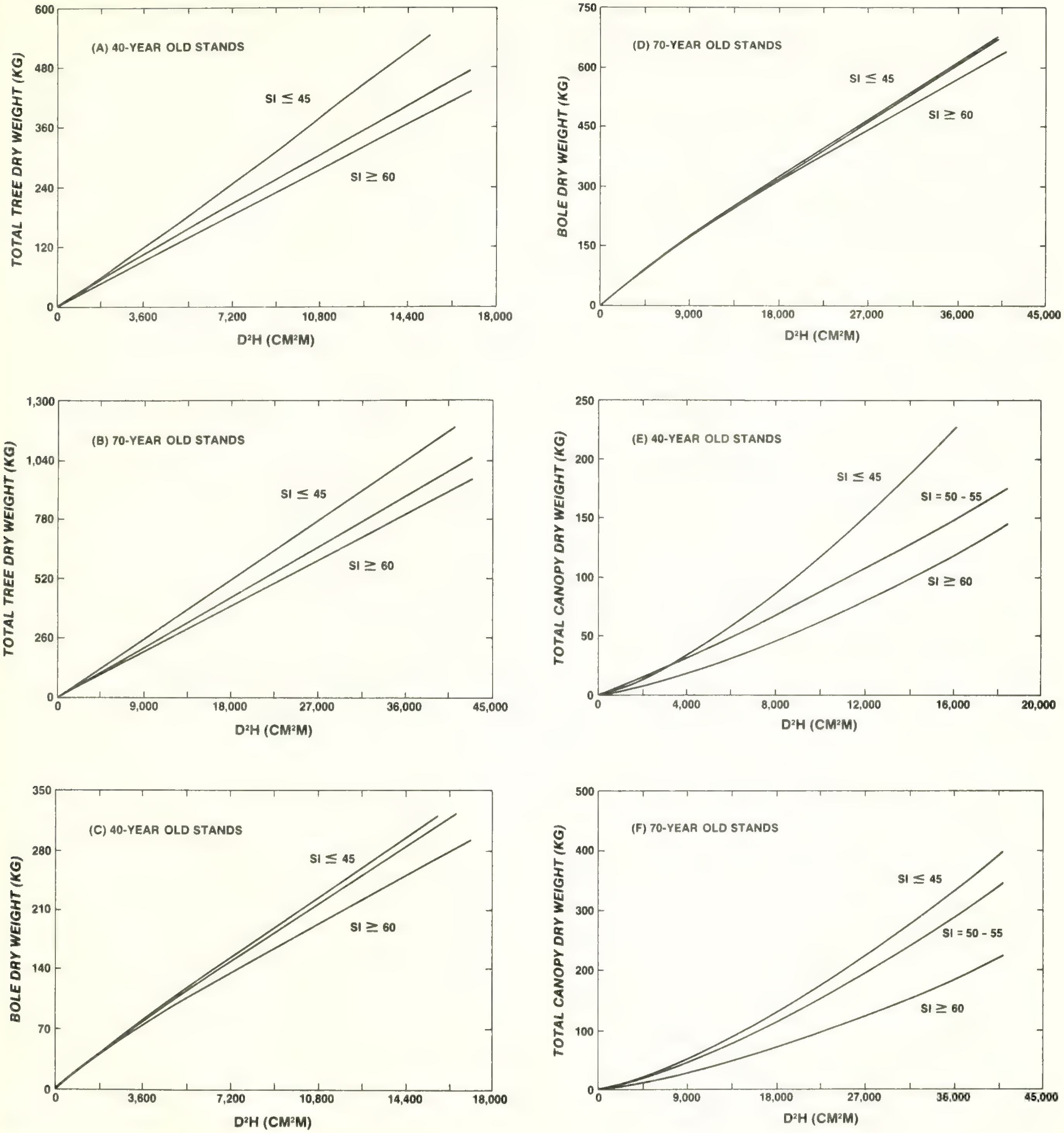

Figure 1.—*Comparison of allometric relation between D^2H and (A) total tree dry weight for 40-year-old stands; (B) total tree dry weight for 70-year-old stands; (C) bole dry weight for 40-year-old stands; (D) bole dry weight for 70-year-old stands; (E) canopy dry weight for 40-year-old stands; and (F) canopy dry weight for 70-year-old stands.*

Table 6—dry weight-metric, stand age~70 years,
Table 7—green weight—English, stand age~40 years,
Table 8—green weight—English, stand age~70 years,
Table 9—dry weight—English, stand age~40 years,
Table 10—dry weight—English, stand age~70 years.

With d.b.h.-dry weight as the variables, differences among sites were so small (fig. 2) that the individual curves provided little additional resolution and the common regression in table 2 was used to generate the values in table 11.

The term forest residuals applies to recoverable and usable materials left in the forest following harvest. Equations presented in table 12 can be used to

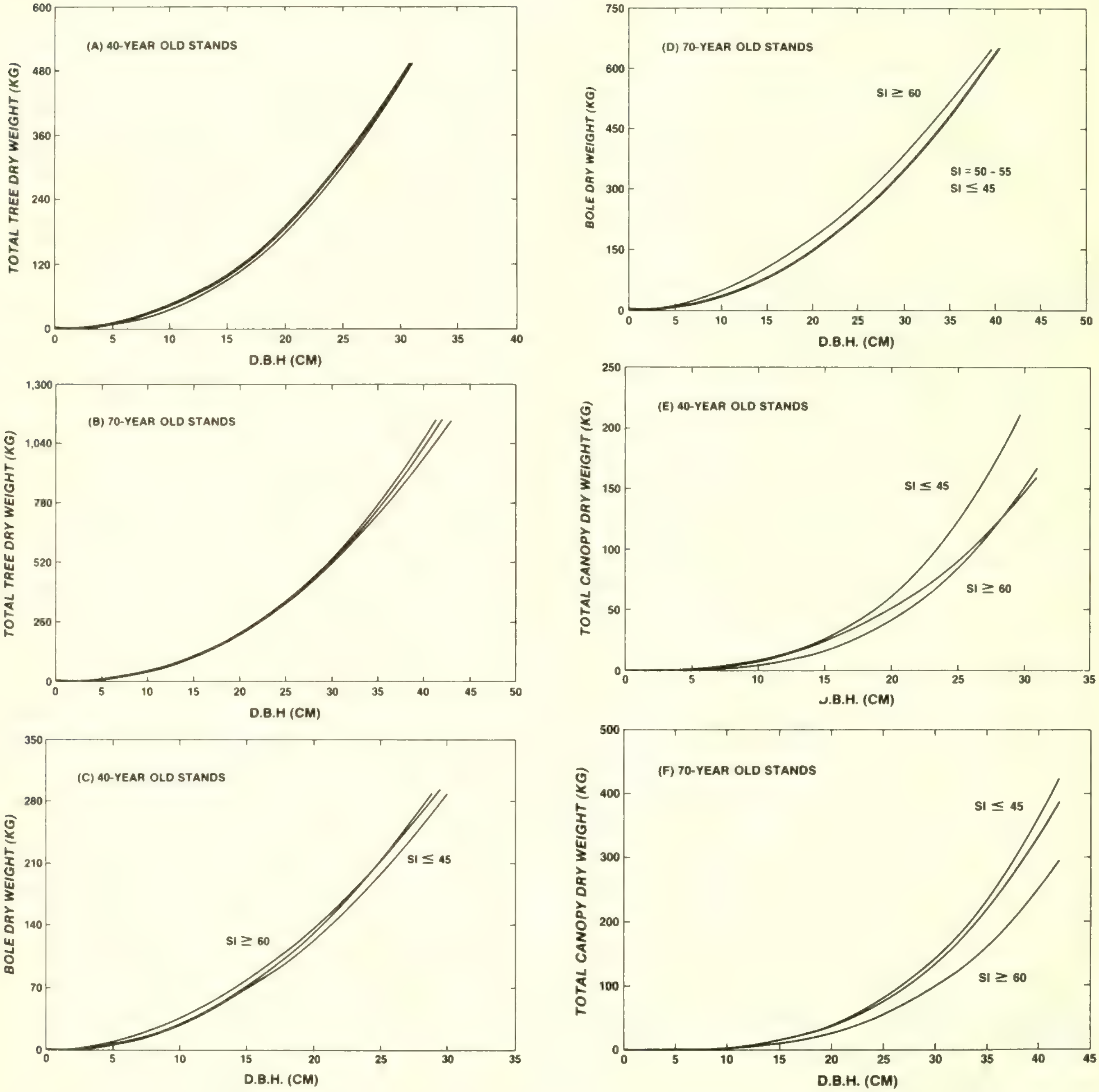

Figure 2.—*Allometric relations between d.b.h. and (A) total tree dry weight for 40-year-old stands; (B) total tree dry weight for 70-year-old stands; (C) bole dry weight for 40-year-old stands; (D) bole dry weight for 70-year-old stands; (E) total canopy for 40-year-old stands; and (F) total canopy for 70-year-old stands.*

predict residual green weight above a 4-inch top, including canopy weight.

The percentage of total weight represented by residual material differs greatly with tree size (fig. 3). The percentage of residual weight declines rapidly as tree size increases and it becomes constant at 22-24 percent in the 18 to 26 cm d.b.h. range. The increase observed for the largest size classes reflects the two-aged nature of most second-growth hardwood stands. The second-growth stands originated in most part from commercial clearcuts in which a number of smaller stems or culls were not cut. As dominants in the new stand, these residual trees often developed large crowns and thus have large residual weights. On the average, approximately a 30 percent increase in harvest yield would result for red maple if residual weight is harvested along with merchantable weight (above 1-foot stump to a 4-inch top) in a full-tree harvest.

In addition to estimates of individual tree weight, weight yields can be estimated from stand measurements. Stand weights were estimated as a function of stand basal area (B) and average total stand height (H), and were expressed as a composite index (BH) in a linear regression (fig. 4). Stand estimates were derived by summing individual tree estimates on 32-1,000 m^2 plots located on the six sample sites. Individual tree regressions developed in our study were applied to red maple. Published regressions were utilized for the other species (Zavitkovski 1971, Crow 1977). From estimates of total stand weight (dry weight of stump, bole, and canopy), estimates of merchantable stem weight to various top diameters (inside bark) can be obtained by applying the ratios of merchantable weight:total weight presented in figure 5. These asymptotic equations estimate the proportions of merchantable weight as a function of average stand diameter and merchantable top diameter.

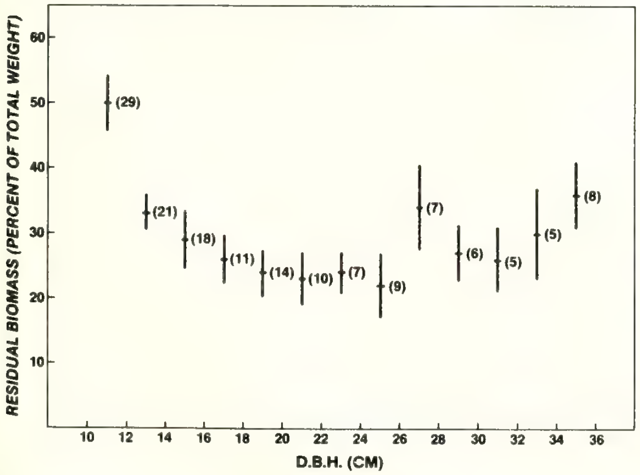

Figure 3.—*Residual biomass as a percentage of total aboveground biomass presented as mean with ± 1SD by diameter class (e.g. ≥ 10 < 12 cm d.b.h....). Values in parentheses represent number of samples in diameter class. Residual biomass is defined as tops above 4-inch diameter inside bark, branches, and foliage.*

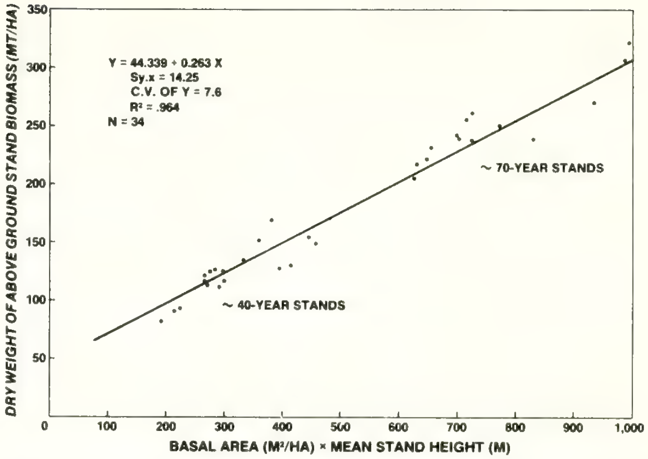

Figure 4.—*Stand dry weight expressed as a linear function of mean stand height and stand basal area for forests dominated by red maple.*

For example, a stand with 35 m^2/ha (152 ft^2/a) of basal area and a mean height (based on dominants and codominants) of 21 m (69 ft) has an estimated aboveground stand weight equal to 238 mt/ha (aboveground stand dry weight = 44.339 + 0.263 (735) from figure 4). Given an average stand diameter of 8.5 inches and a 4-inch utilization limit, the ratio of merchantable weight to total dry weight obtained in figure 5 is 0.66. Thus, 0.66 x 238 = 157 mt/ha (70 short tons/a) represents the merchantable dry weight of the stand.

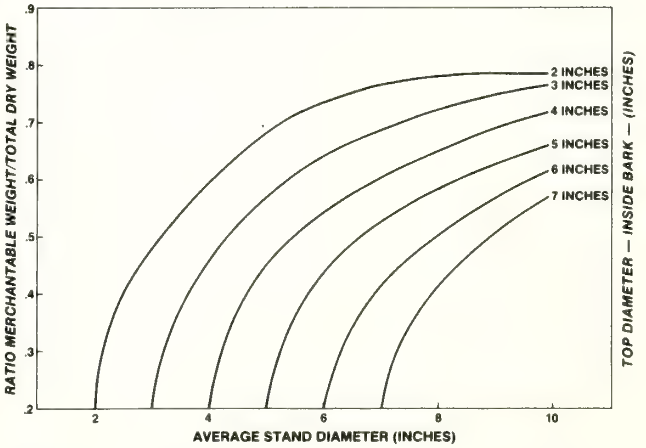

Figure 5.—*The ratio of merchantable weight to total aboveground dry weight expressed as a function of average stand d.b.h. and top diameter inside bark.*

Regression equations for estimating volume did not differ significantly among the sample sites, and thus a single predictor was developed for all sites. Stem volume inside bark and outside bark as well as volume inside bark to 8-inch and 4-inch tops can be estimated using the equations in table 13. The equation for volume to an 8-inch top is based on a variable length stem. Volume estimates to a 4-inch top are based on full 100-inch sticks, with a minimum of 4-inches inside bark for the top 100-inch stick.

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Table 1.—*Characteristics of sample stands and sample trees*

					Sample trees—red maple			
					D.b.h.		Total height	
Stand location	Stand age	Site index[1]	Red maple	Other species	Mean	Range	Mean	Range
	Years		---*Stems/ha*---		---------*cm*---------		-----------*m*-----------	
Wetmore, MI	40	≤ 45	685	537	13.7	10.0-26.6	13.85	12.63-16.60
Sugar Bush, MI	40	50-55	564	412	13.7	10.0-24.6	13.83	12.23-15.90
Eagle River, WI	40	≥ 60	483	407	17.1	10.0-33.2	17.70	13.65-20.74
Rock River, MI	70	≤ 45	607	41	24.0	10.4-46.1	19.42	12.14-22.65
Argonne, WI	70	50-55	643	167	20.5	10.5-36.2	19.74	15.10-23.10
Silver Falls, MI	70	≥ 60	478	305	28.5	14.0-52.2	24.92	18.08-26.84

[1] Site Index–feet at age 50.

Table 2.—*General biomass predictors for red maple in the Lake States (regression model: $\ln Y = a + b \ln X$; ln = natural logarithms; $N = 150$; where Y = weight, X = d.b.h. or D^2H)*

Dependent variable	Independent variable	Intercept (a)	Slope (b)	r^2	$S_{y \cdot x}$[1]	Correction factor[2]
		Dry Weight-kilograms				
Total tree	D.b.h.(cm)	-1.721	2.334	0.98	0.116	1.007
Bole wood	D.b.h.	-1.833	2.234	.97	.152	1.012
Bole bark	D.b.h.	-3.207	1.985	.95	.186	1.017
Total bole	D.b.h.	-1.637	2.207	.97	.150	1.011
Leaves	D.b.h.	-3.288	1.540	.54	.569	1.173
Branches	D.b.h.	-4.899	2.831	.85	.479	1.120
Total canopy	D.b.h.	-4.385	2.701	.84	.471	1.116
Total tree	D^2H(cm^{2}m)	-3.008	.928	.98	.139	1.009
Bole wood	D^2H	-3.158	.898	.99	.104	1.005
Bole bark	D^2H	-4.404	.801	.97	.142	1.010
Total bole	D^2H	-2.943	.888	.99	.099	1.005
Leaves	D^2H	-3.648	.556	.44	.627	1.213
Branches	D^2H	-6.128	1.087	.79	.568	1.173
Total canopy	D^2H	-5.539	1.035	.77	.559	1.166
		Dry Weight-pounds				
Total tree	D.b.h.(inches)	1.245	2.334	.98	.116	1.007
Bole wood	D.b.h.	1.040	2.234	.97	.152	1.012
Bole bark	D.b.h.	-0.566	1.985	.95	.186	1.017
Total bole	D.b.h.	1.211	2.206	.97	.150	1.011
Leaves	D.b.h.	-1.062	1.540	.54	.569	1.173
Branches	D.b.h.	-1.469	2.831	.85	.479	1.120
Total canopy	D.b.h.	-1.077	2.701	.84	.471	1.116
Total tree	D^2H(in^{2}ft)	-1.545	.923	.97	.169	1.014
Bole wood	D^2H	-1.715	.894	.98	.135	1.009
Bole bark	D^2H	-3.038	.797	.96	.161	1.129
Total bole	D^2H	-1.513	.883	.98	.131	1.008
Leaves	D^2H	-2.434	.550	.43	.631	1.217
Branches	D^2H	-4.524	1.078	.77	.585	1.184
Total canopy	D^2H	-3.976	1.027	.76	.574	1.176
		Green Weight-kilograms				
Total tree	D.b.h.(cm)	-1.249	2.320	.99	.112	1.006
Total bole	D.b.h.	-1.123	2.177	.93	.239	1.029
Branches	D.b.h.	-4.712	2.885	.86	.464	1.112
Leaves	D.b.h.	-2.617	1.592	.58	.537	1.153
Total canopy	D.b.h.	-3.942	2.688	.85	.459	1.109
Total tree	D^2H(cm^{2}m)	-2.539	.924	.98	.127	1.008
Total bole	D^2H	-2.427	.878	.95	.204	1.021
Branches	D^2H	-6.005	1.113	.80	.550	1.161
Leaves	D^2H	-3.026	.579	.48	.597	1.192
Total canopy	D^2H	-5.096	1.031	.78	.546	1.158

(Table 2 continued on next page)

(Table 2 continued)

Dependent variable	Independent variable	Intercept (a)	Slope (b)	r^2	$S_{y \cdot x}$[1]	Correction factor[2]
		Green Weight-pounds				
Total tree	D.b.h.(inches)	1.705	2.320	.99	.112	1.006
Total bole	D.b.h.	1.697	2.177	.93	.239	1.029
Branches	D.b.h.	-1.232	2.885	.86	.464	1.112
Leaves	D.b.h.	-0.343	1.592	.58	.537	1.153
Total canopy	D.b.h.	-0.645	2.688	.85	.459	1.109
Total tree	$D^2H(in^2ft)$	-1.086	.920	.97	.154	1.018
Total bole	D^2H	-1.014	.875	.94	.216	1.023
Branches	D^2H	-4.385	1.104	.79	.567	1.172
Leaves	D^2H	-1.792	.573	.47	.603	1.196
Total canopy	D^2H	-3.537	1.023	.77	.561	1.168

[1] Standard error estimate in $\log_e$ form.

[2] Correction for bias inherent in applying logarithmic transformations; $\hat{Y}_{adj} = (\exp(a + b \cdot \ln x)) \cdot K$ (Beauchamp and Olson 1973).

Table 3.—*Total tree green weight of red maple trees (stand age ~ 40 years)*

(In kilograms)

D.b.h. (cm)	Total tree height (meters) 12	14	16	18	20	22
SI $\leq$ 45 EQUATION: Log_e (total tree wt) = -2.888 + 0.975 Log_e (D^2H)						
10	56	65	74	83	92	101
12	80	93	106	119	131	144
14	108	125	143	160	178	195
16	140	163	185	208	230	253
18	176	205	233	261	290	318
20	216	251	286	321	356	391
22	260	303	345	387	429	470
24	309	359	408	458	508	557
26	361	419	477	536	594	651
28	417	484	552	619	686	753
30	477	554	631	708	785	861
SI 50-55 EQUATION: Log_e (total tree wt) = -2.933 + 0.975 Log_e (D^2H)						
10	54	62	71	79	88	97
12	76	89	101	113	126	138
14	103	103	137	153	170	186
16	134	155	177	199	220	242
18	168	196	223	250	277	304
20	207	240	274	307	340	373
22	249	289	330	370	410	450
24	295	343	391	438	485	533
26	345	401	456	512	567	623
28	398	463	527	592	656	720
30	456	530	603	677	750	823
SI $\geq$ 60 EQUATION: Log_e (total tree wt) = -2.978 + 0.975 Log_e (D^2H)						
10	51	59	68	76	84	92
12	73	85	97	108	120	132
14	99	115	131	146	162	178
16	128	149	169	190	210	231
18	161	187	213	239	265	291
20	198	230	262	293	325	357
22	238	277	315	353	392	430
24	282	328	373	419	464	509
26	330	383	436	490	542	595
28	381	443	504	566	627	688
30	436	506	577	647	717	787

Table 4.—*Total tree green weight of red maple trees (stand age ~ 70)*

(In kilograms)

D.b.h. (cm)	Total tree height (meters) 16	18	20	22	24	26
SI $\leq$ 45 EQUATION: Log_e (total tree wt) = -3.211 + 1.002 Log_e (D^2H)						
14	128	145	161	177	193	209
16	168	189	210	231	252	273
18	213	239	266	293	319	346
20	263	295	328	361	394	427
22	318	358	397	437	477	517
24	378	426	473	521	568	615
26	444	500	556	611	667	723
28	515	580	644	709	774	838
30	592	666	740	814	888	963
32	673	758	842	927	1011	1095
34	760	856	951	1046	1142	1237
SI 50-55 EQUATION: Log_e (total tree wt) = -3.286 + 1.002 Log_e (D^2H)						
14	119	134	149	164	179	194
16	156	175	195	214	234	253
18	197	222	247	271	296	321
20	244	274	305	335	366	396
22	295	332	369	406	443	480
24	351	395	439	483	527	571
26	412	464	515	567	619	670
28	478	538	598	658	718	778
30	549	618	687	755	824	893
32	625	703	781	860	938	1016
34	706	794	882	971	1059	1148
SI $\geq$ 60 EQUATION: Log_e (total tree wt) = -3.361 + 1.002 Log_e (D^2H)						
14	111	124	138	152	166	180
16	145	163	181	199	217	235
18	183	206	229	252	275	298
20	226	254	283	311	339	368
22	274	308	342	376	411	445
24	326	366	407	448	489	530
26	382	430	478	526	574	622
28	444	499	555	610	666	722
30	509	573	637	701	765	828
32	580	652	725	798	870	943
34	655	737	819	901	983	1065

Table 5.—*Total tree dry weight of red maple trees (stand age ~ 40 years)*

(In kilograms)

D.b.h. (cm)	Total tree height (meters)					
	12	14	16	18	20	22
SI ≤ 45 EQUATION: Log_e(total tree wt) = -3.498 + 1.002 Log_e(D.b.h.^{2})(Ht)						
10	37	43	49	55	61	68
12	53	62	71	80	89	97
14	72	84	96	109	121	133
16	94	110	126	142	158	173
18	120	140	160	180	200	220
20	148	172	197	222	246	271
22	179	209	239	268	298	328
24	213	248	284	320	355	391
26	250	292	333	375	417	459
28	290	338	387	435	484	532
30	333	389	444	500	555	611
SI 50-55 EQUATION: Log_e(total tree wt) = -3.581 + 1.002 Log_e(D.b.h.^{2})(Ht)						
10	34	40	45	51	57	62
12	49	57	65	73	81	90
14	67	78	89	100	111	122
16	87	101	116	131	145	160
18	110	128	147	165	184	202
20	136	159	181	204	227	250
22	165	192	220	247	275	302
24	196	229	261	294	327	360
26	230	268	307	345	384	422
28	267	311	356	401	445	490
30	306	358	409	460	511	562
SI ≥ 60 EQUATION: Log_e(total tree wt) = -3.663 + 1.002 Log_e (D.b.h.^{2})(Ht)						
10	31	36	42	47	52	57
12	45	53	60	68	75	83
14	61	72	82	92	102	112
16	80	93	107	120	134	147
18	101	118	135	152	169	186
20	125	146	167	188	209	230
22	152	177	202	228	253	278
24	180	211	241	271	301	331
26	212	247	283	318	354	389
28	246	287	328	369	410	451
30	282	329	377	424	471	518

Table 6.—*Total tree dry weight of red maple trees (stand age ~ 70 years)*

(In kilograms)

D.b.h. (cm)	Total tree height (meters)					
	16	18	20	22	24	26
SI ≤ 45 EQUATION: Log_e(total tree wt) = -3.698 + 1.008 Log_e(D^2H)						
14	83	93	104	114	125	135
16	108	122	136	150	163	177
18	138	155	172	190	207	224
20	170	192	213	234	256	277
22	206	232	258	284	310	336
24	246	277	308	339	370	401
26	289	325	361	398	434	471
28	335	377	420	462	504	547
30	385	434	482	531	580	628
32	439	494	549	605	660	716
34	496	558	621	683	746	809
SI 50-55 EQUATION: Log_e(total tree wt) = -3.788 + 1.008 Log_e(D^2H)						
14	76	85	95	104	114	124
16	99	112	124	137	149	162
18	126	142	157	173	189	205
20	155	175	195	214	234	254
22	188	212	236	260	283	307
24	224	253	281	309	338	366
26	264	297	330	364	397	430
28	306	345	384	422	461	500
30	352	396	441	485	530	574
32	401	451	502	553	603	654
34	453	510	567	624	682	739
SI ≥ 60 EQUATION: Log_e(total tree wt) = -3.878 + 1.008 Log_e (D^2H)						
14	69	78	87	95	104	113
16	91	102	113	125	136	148
18	115	129	144	158	173	187
20	142	160	178	196	214	232
22	172	194	216	237	259	281
24	205	231	257	283	309	335
26	241	271	302	332	363	393
28	280	315	351	386	421	457
30	322	362	403	443	484	525
32	366	413	459	505	551	598
34	414	466	518	571	623	675

Table 7.—*Total tree green weight of red maple trees (stand age ~ 40 years)*

(In pounds)

D.b.h.	Total tree height (feet)							
(in)	30	35	40	45	50	55	60	65
SI ≤ 45 EQUATION: $\text{Log}_e(\text{total tree wt}) = -1.709 + 1.025\,\text{Log}_e(D^2H)$								
2	24	29	33	37	41	46	50	54
4	101	119	136	154	171	189	206	224
6	233	273	313	353	393	433	474	514
8	420	492	564	636	709	782	855	928
10	663	777	891	1,005	1,120	1,235	1,350	1,466
12	964	1,129	1,295	1,461	1,628	1,795	1,962	2,130
14	1,323	1,549	1,776	2,004	2,233	2,462	2,691	2,921
16	1,739	2,037	2,335	2,635	2,935	3,237	3,539	3,841
SI 50-55 EQUATION: $\text{Log}_e(\text{total tree wt}) = -1.882 + 1.025\,\text{Log}_e(D^2H)$								
2	21	24	28	31	35	38	42	45
4	85	100	115	129	144	159	174	188
6	196	229	263	297	331	365	399	433
8	353	414	474	535	596	657	719	780
10	558	654	749	846	942	1,039	1,136	1,233
12	811	950	1,089	1,229	1,369	1,510	1,650	1,791
14	1,112	1,303	1,494	1,686	1,878	2,071	2,264	2,457
16	1,463	1,713	1,964	2,216	2,469	2,723	2,977	3,231
SI ≥ 60 EQUATION: $\text{Log}_e(\text{total tree wt}) = -2.054 + 1.025\,\text{Log}_e(D^2H)$								
2	17	20	23	26	29	32	35	38
4	72	84	96	109	121	134	146	159
6	165	193	221	250	278	307	336	364
8	297	348	399	451	502	554	605	657
10	470	550	631	712	793	875	956	1,038
12	683	800	917	1,035	1,153	1,271	1,390	1,508
14	937	1,097	1,258	1,419	1,581	1,743	1,906	2,069
16	1,232	1,442	1,654	1,866	2,079	2,292	2,506	2,720

Table 8.—*Total tree green weight of red maple trees (stand age ~ 70 years)*

(In pounds)

D.b.h.	Total tree height (feet)							
(in)	45	50	55	60	65	70	75	80
SI ≤ 45 EQUATION: $\text{Log}_e(\text{total tree wt}) = -1.519 + 0.978\,\text{Log}_e(D^2H)$								
4	136	151	166	181	195	210	225	239
6	301	335	367	399	432	464	497	529
8	529	587	644	701	758	815	872	929
10	819	908	996	1,085	1,173	1,261	1,349	1,437
12	1,170	1,297	1,423	1,550	1,676	1,802	1,928	2,053
14	1,581	1,753	1,924	2,095	2,265	2,436	2,606	2,776
16	2,053	2,276	2,498	2,720	2,942	3,163	3,384	3,604
18	2,585	2,866	3,146	3,425	3,704	3,982	4,260	4,538
SI 50-55 EQUATION: $\text{Log}_e(\text{total tree wt}) = -1.609 + 0.978\,\text{Log}_e(D^2H)$								
4	125	138	152	165	179	192	205	219
6	276	305	335	365	395	424	454	484
8	484	536	588	641	693	745	797	849
10	748	829	911	991	1,072	1,153	1,233	1,314
12	1,069	1,185	1,301	1,416	1,532	1,647	1,762	1,876
14	1,445	1,602	1,758	1,915	2,071	2,226	2,382	2,537
16	1,876	2,080	2,283	2,486	2,688	2,891	3,092	3,294
18	2,363	2,619	2,875	3,130	3,385	3,639	3,894	4,147
SI ≥ 60 EQUATION: $\text{Log}_e(\text{total tree wt}) = -1.699 + 0.978\,\text{Log}_e(D^2H)$								
4	114	126	139	151	163	175	188	200
6	252	279	306	334	361	388	415	442
8	442	490	538	586	633	681	728	776
10	684	758	832	906	980	1,054	1,127	1,200
12	977	1,083	1,189	1,294	1,400	1,505	1,610	1,715
14	1,321	1,464	1,607	1,750	1,892	2,035	2,177	2,318
16	1,715	1,901	2,087	2,272	2,457	2,642	2,826	3,010
18	2,159	2,394	2,627	2,861	3,094	3,326	3,558	3,790

Table 9.—*Total tree dry weight of red maple trees (stand age ~ 40 years)*

(In pounds)

D.b.h.	Total tree height (feet)							
(in)	30	35	40	45	50	55	60	65
SI ≤ 45 EQUATION: Log_e (total tree wt) = $-1.959 + 0.996 \ln(D^2H)$								
2	17	19	22	25	28	30	33	36
4	66	77	88	99	110	121	132	143
6	148	173	197	222	246	271	295	320
8	263	306	350	393	437	480	524	567
10	410	478	546	614	681	749	817	885
12	589	687	785	882	980	1,077	1,175	1,275
14	801	934	1,066	1,199	1,332	1,465	1,597	1,730
16	1,045	1,218	1,391	1,565	1,738	1,911	2,084	2,257
SI 50-55 EQUATION: Log_e (total tree wt) = $-2.034 + 0.996 \ln(D^2H)$								
2	15	18	21	23	26	28	31	33
4	61	71	82	92	102	112	122	132
6	137	160	183	206	229	251	274	297
8	244	284	325	365	405	446	486	526
10	380	443	506	569	632	695	758	821
12	546	637	728	818	909	999	1,090	1,180
14	743	866	989	1,113	1,236	1,359	1,482	1,605
16	969	1,130	1,291	1,452	1,612	1,773	1,933	2,094
SI ≥ 60 EQUATION: Log_e (total tree wt) = $-2.109 + 0.996 \ln(D^2H)$								
2	14	17	19	21	24	26	28	31
4	57	66	76	85	95	104	113	123
6	127	149	170	191	212	233	254	275
8	226	264	301	339	376	413	451	488
10	353	411	470	528	586	645	703	762
12	507	591	675	759	843	927	1,011	1,095
14	689	804	918	1,032	1,146	1,261	1,375	1,489
16	899	1,049	1,198	1,347	1,496	1,645	1,794	1,942

Table 10.—*Total tree dry weight of red maple trees (stand age ~ 70 years)*

(In pounds)

D.b.h.	Total tree height (feet)							
(in)	45	50	55	60	65	70	75	80
SI ≤ 45 EQUATION: Log_e (total tree wt) = $-1.990 + 0.981 \ln(D^2H)$								
4	87	96	106	115	125	134	143	153
6	192	213	234	255	276	297	318	338
8	338	375	412	449	485	522	559	595
10	524	581	638	695	752	809	865	922
12	750	831	913	994	1,075	1,157	1,237	1,318
14	1,015	1,125	1,235	1,345	1,455	1,565	1,675	1,784
16	1,318	1,462	1,605	1,748	1,891	2,034	2,176	2,318
18	1,661	1,842	2,023	2,203	2,383	2,562	2,742	2,921
SI 50-55 EQUATION: Log_e (total tree wt) = $-2.095 + 0.981 \ln(D^2H)$								
4	78	87	95	104	112	121	129	138
6	173	192	211	230	249	267	286	305
8	305	338	371	404	437	470	503	536
10	472	523	575	626	677	728	779	830
12	675	749	822	895	968	1,041	1,114	1,187
14	913	1,013	1,112	1,211	1,310	1,409	1,508	1,606
16	1,187	1,316	1,445	1,574	1,703	1,831	1,959	2,087
18	1,496	1,658	1,821	1,983	2,145	2,307	2,468	2,630
SI ≥ 60 EQUATION: Log_e (total tree wt) = $-2.200 + 0.981 \ln(D^2H)$								
4	70	78	86	93	101	109	116	124
6	156	173	190	207	224	241	257	274
8	274	304	334	364	393	423	453	482
10	425	471	517	564	610	656	701	747
12	608	674	740	806	872	937	1,003	1,069
14	822	912	1,001	1,090	1,180	1,269	1,357	1,446
16	1,069	1,185	1,301	1,417	1,533	1,648	1,764	1,879
18	1,346	1,493	1,639	1,786	1,931	2,077	2,222	2,368

Table 11.—*Total tree weight—d.b.h. (N=150)*

Green weight[1]

Equations: $\log_e(\text{total tree wt-kg}) = -1.249 + 2.320 \log_e(\text{D.b.h.-cm})$

$\log_e(\text{total tree wt-lbs}) = 1.705 + 2.320 \log_e(\text{D.b.h.-in.})$

D.b.h.	Weight	D.b.h.	Weight
cm	*kg*	*in.*	*lbs*
10	60	4	138
12	92	5	231
14	132	6	353
16	179	7	505
18	236	8	689
20	301	9	905
22	375	10	1,156
24	459	11	1,442
26	553	12	1,765
28	657	13	2,125
30	771	14	2,524
32	896	15	2,962
34	1,031	16	3,440
36	1,177	17	3,960
38	1,334	18	4,522
40	1,503	19	5,126
42	1,683	20	5,774

Dry weight[1]

Equations: $\text{Log}_e(\text{total tree wt-kg}) = -1.721 + 2.334 \text{ Log}_e(\text{D.b.h.-cm})$

$\text{Log}_e(\text{total tree wt-lbs}) = 1.245 + 2.334 \text{ Log}_e(\text{D.b.h.-in.})$

D.b.h.	Weight	D.b.h.	Weight
cm	*kg*	*in.*	*lbs*
10	39	4	89
12	59	5	150
14	85	6	229
16	116	7	328
18	153	8	448
20	196	9	590
22	245	10	754
24	300	11	943
26	361	12	1,155
28	430	13	1,392
30	505	14	1,655
32	587	15	1,944
34	676	16	2,260
36	773	17	2,604
38	877	18	2,975
40	988	19	3,375
42	1,107	20	3,805

[1] Correction factors have been applied to weight estimates; K=1.007.

Table 12.—*Residual weight (green) assuming 4 inch top diameter inside bark; residue = canopy weight + bole weight above 4-inch top*

Stand age/SI	Equations[1]
	Y = green weight (kg); X = d.b.h. (cm)[2]
40 ≤ 45	$\ln Y = -0.903 + 1.811 \ln \text{D.b.h.}$
40 50-55	$\ln Y = 0.111 + 1.395 \ln \text{D.b.h.}$
40 ≥ 60	$\ln Y = -1.264 + 1.909 \ln \text{D.b.h.}$
70 ≤ 45	$\ln Y = -2.512 + 2.338 \ln \text{D.b.h.}$
70 50-55	$\ln Y = -1.746 + 2.044 \ln \text{D.b.h.}$
70 ≥ 60	$\ln Y = -4.385 + 2.801 \ln \text{D.b.h.}$
	Y = green weight (kg); $X = D^2H$ (cm^{2}m)[2]
40 ≤ 45	$\ln Y = -2.533 + 0.811 \ln D^2H$
40 50-55	$\ln Y = -0.895 + 0.595 \ln D^2H$
40 ≥ 60	$\ln Y = -2.555 + 0.786 \ln D^2H$
70 ≤ 45	$\ln Y = -4.179 + 0.975 \ln D^2H$
70 50-55	$\ln Y = -3.492 + 0.876 \ln D^2H$
70 ≥ 60	$\ln Y = -6.769 + 1.190 \ln D^2H$

[1] ln = natural logarithms, base e.

[2] For conversion to English units:
kg x 2.2046 = pounds
cm x 0.3937 = inches
m x 3.2808 = feet

Table 13.—*Regression equations for estimating stem volume of red maples; Y = cubic volume in m³*

Equation[1]	r^2	$S_{yy \cdot x}$	Correction factor (K)[2]
Y = volume (m^3) outside bark–total stem			
X = d.b.h. (cm)			
sample number (N) = 331			
$Y = -0.012 + 0.00075(X^2)$	0.92	0.085	
$\ln Y = -7.900 + 2.207(\ln x)$	.95	.207	1.022
Y = volume (m^3) outside bark–total stem			
$X = D^2H$ (cm^2m)			
N = 331			
$Y = 0.042 + 0.000031(X)$	.89	.097	–
$\ln Y = -9.403 + 0.910(\ln X)$	.95	.194	1.019
Y = volume (m^3) inside bark–total stem			
X = d.b.h. (cm)			
N = 331			
$Y = -0.011 + 0.00067(X^2)$	.91	.075	–
$\ln Y = -8.210 + 2.271(\ln X)$	.93	.248	1.031
Y = volume (m^3) inside bark–total stem			
$X = D^2H$ (cm^2m)			
N = 331			
$Y = 0.037 + 0.000028(X)$	.90	.084	–
$\ln Y = -9.759 + 0.937(\ln X)$	.94	.236	1.028
Y = volume (m^3) inside bark–above 1-ft stump to 8-inch top			
X = d.b.h. (cm)			
N = 84			
$Y = -0.181 + 0.000577(X^2)$	.86	.096	–
$\ln Y = -12.544 + 3.338(\ln X)$	.83	.277	1.038
Y = volume (m^3) inside bark–above 1-ft stump to 8-inch top			
$X = D^2H$ (cm^2m^2)			
N = 84			
$Y = -0.108 + 0.000023(X)$	.86	.096	–
$\ln Y = -15.391 + 1.437(\ln X)$	.82	.289	1.042
Y = volume (m^3) inside bark–above 1-ft stump to 4-inch top			
X = d.b.h. (cm)			
N = 262			
$Y = -0.037 + 0.000057(X^2)$	.92	.064	–
$\ln Y = -9.967 + 2.732(\ln X)$	.89	.319	1.052
Y = volume (m^3) inside bark–above 1-ft stump to 4-inch top			
$X = D^2H$ (cm^2m)			
N = 262			
$Y = 0.0052 + 0.000024(X)$	.93	.060	–
$\ln Y = -11.970 + 1.142(\ln X)$	.90	.308	1.048

[1] $\ln = \log_e$

[2] $Y_{adj} = (\exp(a + b \cdot \ln X)) \cdot K$

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North Central Forest Experiment Station

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Michigan's Predicted Timber Yields 1981-2010

Pamela J. Jakes and W. Brad Smith

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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FOREWORD

Forest Inventory Analysis (FIA) is a continuing effort mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974 (P.L. 93-378). One objective of the Act is the evaluation of timber management opportunities. In partial fulfillment of this objective, treatment opportunities were analyzed for Michigan forest conditions projected for the period 1981-2010.

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MICHIGAN'S PREDICTED TIMBER YIELDS 1981-2010

Pamela J. Jakes, *Resource Analyst,*
and **W. Brad Smith,** *Mensurationist*

Efficient management of Michigan's timber resource today depends, in part, on the knowledge of what is likely to happen in the future—can supplies of timber continue to increase, will demand for forest resources increase? In an effort to answer questions concerning potential timber supply, we projected Michigan's forest resources 30 years into the future. We identified forest stands qualifying for harvest, thinning, or timber stand improvement (t.s.i.) during the projection period constrained by area control, and then we predicted timber yields from these activities.

We refer to these predicted yields from all management activities as our estimate of long-term timber supply. Long-term timber supply was calculated by using only medium- to well-stocked timber stands—poorly stocked stands were removed from the projection data base and placed in the treatment category identified as stand conversion or restocking. After presenting projection values, we compare our estimate of long-term timber supply to an estimate of long-term timber demand. We also compare 1979 average annual growing-stock removals and average annual growing-stock removals for the decade 1981-1990. We provide examples of how forest managers and planners can gear the study findings to a particular user or region. Finally, we estimate Michigan's sustained yield, including yields from tops and limbs of cut trees.

There is no one correct estimate of timber supply—forest acreage treated or volumes removed during management activities—instead, acreages and volumes vary, according to the treatment criteria specified. This paper presents an area control alternative, which is just one of many possible management scenarios for Michigan's forests.

Michigan's timber resources have played a vital role in the settlement and development of the State. Today, many forest users vie for economic and natural resources.

Michigan's lumber and wood products industries continue to provide jobs and revenue for the State, particularly in areas where alternative employment and investment options may be limited. In 1980 an estimated 60,000 employees were working in Michigan's primary and secondary wood processing industries.[1]

To ensure that Michigan's lumber and wood products industries continue to play a vital role in the State's economy, timber resources must be managed and used efficiently.

ASSUMPTIONS

Two assumptions are essential to this study: (1) all commercial forest land is available for treatment and (2) markets exist for all species and products. The analysis does not consider possible economic, social, or political constraints on timber removals. Nor does it address increased utilization through improved technology, intensified management, or genetically improved stock. Harvest treatment opportunities and predicted yields are based on an area control model—assuming that it is desirable to have an even distribution of acreage by age class within each forest type by the end of one rotation.

METHODS

The process of determining silvicultural treatment opportunities for Michigan involved four steps: (1) modify an existing computerized tree growth model to handle the Michigan inventory data and special output requirements; (2) select treatment options and define treatment criteria; (3) project commercial forest area for the next 30 years; and (4) project the current inventory, assess treatment options, and produce summary tables. Each step of the process is described in detail below.

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[1] *Michigan Department of Natural Resources.*

Modify STEMS

[illegible] and Modeling System (STEMS) is a set of computer programs for projecting the growth of forest stands in the Lake States (later versions will include other geographic regions) for any combination of tree species and sizes. Three modifications were made in STEMS for the Michigan 30-year projection.

[illegible] local conditions. Calibration data were obtained from plots established in 1966 and remeasured during the 1980 Michigan forest inventory. Calibration data were validated by using an independent data set.

Second, the computerized Lake States management algorithm in STEMS was replaced by an algorithm developed specifically for Michigan. This algorithm was developed by using management criteria discussed in detail below—only in the case of t.s.i. were the STEMS management guides left intact. Processing within the management algorithm was also modified to handle harvest projections under an area control model with a changing commercial for-[illegible]

Finally, an output algorithm was developed that would produce the desired tables. Tables produced for each Survey Unit and each decade of the projection period summarize information on the areas qualifying for harvest, thinning, and t.s.i. as well as information on the volumes that would be removed during treat[illegible]tions.

Define Management Criteria

Treatment options and criteria were determined during discussions with representatives of the Michigan Department of Natural Resources (MDNR). Four treatments were considered for the Michigan projection: (1) harvest, (2) thinning, (3) t.s.i., and (4) stand conversion or restocking. Definitions of each [illegible] and descriptions of treatment criteria follow.

Harvest

Harvest is the final cut in a forest stand. To facilitate the use of the area control method, the final cut in all forest types was a clearcut. Because we assumed that all harvests are followed by natural or [illegible]

The harvest area for any forest type is set by an area control algorithm. The area control algorithm sets the harvest acreage for each decade and for each forest type so that the type area will be evenly distributed among age classes by the end of one rotation.

The annual area control harvest acreage is determined for each forest type by dividing the number of acres in a forest type by the type's rotation age. Harvest acreage for the decade is 10 times the annual area control harvest acreage. The rotation age for each forest type was set by the MDNR (table 1). Rotation ages used in this analysis are from a harvest schedule that State officials feel best represents current or desired management practices.

Thinning

In this report, thinning is a partial cut of commercial material before the final harvest cut. Criteria for scheduling thinning include stand age and basal area. For the red pine and white pine forest types, the MDNR assigned pre-thinning and post-thinning basal areas (table 1). For the balsam fir, white spruce, oak-hickory, and maple-birch forest types, STEMS thinning criteria were used (Brand 1981). Thinning is not considered a viable treatment option in the jack pine, black spruce, northern white-cedar, tamarack, or exotic forest types.

Stands within 10 years of rotation age were not considered for thinning because we assumed that it would not be feasible to thin a stand and then return in less than 10 years for final harvest.

Timber Stand Improvement

The t.s.i. treatment category is made up of management operations that have traditionally been thought of as noncommercial or precommercial—such as the weeding, cleaning, or releasing of a timber stand. Today, it may be feasible to recover some of the material from t.s.i. for fuelwood or other products. Timber stand improvement treatment criteria built into STEMS were used for assigning t.s.i. in Michigan (table 1). STEMS uses site index, stand age, and basal area to assign t.s.i.

Stand Conversion or Restocking

Stands qualifying for stand conversion or restocking present opportunities for increasing utilization of commercial forest land. Only poorly stocked commercial forest plots were assigned to the stand con[illegible]ng treatment category. Poorly [illegible]ked plots include nonstocked areas where stocking of growing-stock trees is less than 16.7 percent and areas where stand basal area is less than or equal to 19 + 0.38 (stand age). This general equation, developed by Forest Service researchers, identifies non-seedling stands in which stocking, in relation to age, is so low that the stands are not expected to reach a level of stocking adequate for commercial timber production by rotation age.

STEMS was used to project stand and tree characteristics for stocked commercial forest plots only. For each decade, poorly stocked areas were withdrawn from the data base used in STEMS and placed in a separate file. Poorly stocked stands were not included in the data base because it is difficult to assign a meaningful forest type to these stands, and thus is difficult to trace these stands through the projection process. We assumed that these stands are poorly stocked because (1) adverse site conditions dictate extraordinary regeneration efforts or (2) management objectives that preclude timber management are already in place. Because stand and tree characteristics of poorly stocked stands were not projected, volume information for stand conversion or restocking areas is available for 1980 only.

Forecast Changes in Commercial Forest Area

Because harvest treatment areas are selected by an area control algorithm, it is important to have realistic estimates of commercial forest area throughout the projection period. For each Unit we analyzed historical trends in commercial forest area by forest type and projected forest type areas based on these trends. Representatives from the MDNR reviewed the area projections. Their predictions were used when different from those indicated by trend analysis (table 2).

In 1977, commercial forest area was projected for each State through the year 2030 in accordance with R.P.A. requirements (Wall 1981). Forest and Rangeland Renewable Resources Planning Act (R.P.A.) estimates for Michigan were based on the 1966 forest inventory. These area projections underestimated the decline in commercial forest area between 1966 and 1980. R.P.A. estimates place the decline in commercial forest area between 1966 and 1980 at approximately 230,000 acres, but the new inventory shows a 1.4 million-acre decline. By 2010 our estimates of commercial forest area are 2 percent less than the R.P.A. estimates. Because our numbers are based on the most recent forest inventory, we feel they are the most realistic.

Data from 1980 indicate that approximately 6 percent of the commercial forest land in the State is poorly stocked. We assumed that the proportion of poorly stocked commercial forest land to the total commercial forest area would remain constant, at 1980 levels, throughout the projection period. There will always be some poorly stocked areas because of failures in regeneration efforts, weather damage, or other causes of mortality such as insects, fire, and disease. Also, some areas will be poorly stocked because they are being managed as wildlife openings.

Assessing Treatment Options

The logic used to assign treatments to each commercial forest plot is diagrammed in figure 1. Data processing involves four steps. (1) The poorly stocked commercial forest plots are removed from the data base and placed in the stand conversion or restocking treatment class. (2) Inventory tree lists from the remaining stocked commercial forest plots are fed into STEMS. At the beginning of each decade, the area control algorithm assigns the number of acres that must be cut in each forest type during the decade to achieve area control. Plots are arranged in order of stand age. Beginning with overmature stands, STEMS "cuts" plots until the area selected for harvest within each type equals the area control harvest acreage. (3) STEMS then scans the age of all plots remaining after harvest. If the stand is within 10 years of harvest, it is placed in the no treatment category. If the stand age is more than 10 years from harvest, plot characteristics are compared to thinning and t.s.i. criteria to select plots for both treatments. (4) Plots not qualifying for thinning or t.s.i. are placed in the no treatment catgory.

Tables are printed that summarize data on the areas to be treated and volumes expected from those treatments. Tables highlight information that aids data users in modifying the findings to fit conditions or management practices in their areas.

RESULTS

Highlights from the identification of Michigan's projected treatment opportunities, 1981-2010, are presented below by decade and treatment class.

Detailed information is not available by decade for areas receiving no treatment or qualifying for stand conversion or restocking. We can glean some information on the stand conversion/restockin [illegible] from data collected during the fourth Michigan For-

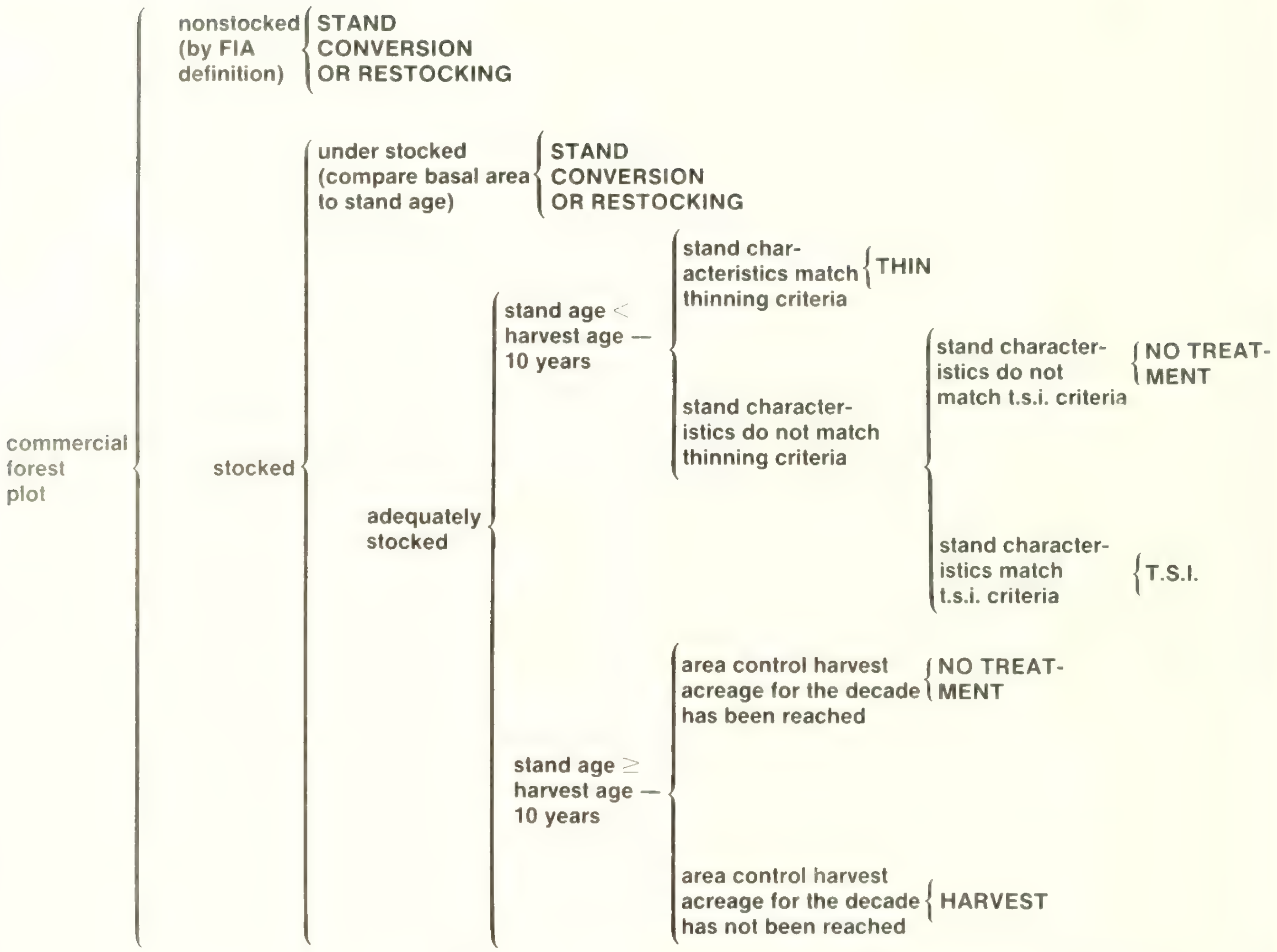
commercial forest plot
nonstocked (by FIA definition)
STAND CONVERSION OR RESTOCKING
stocked
under stocked (compare basal area to stand age)
STAND CONVERSION OR RESTOCKING
adequately stocked
stand age < harvest age — 10 years
stand characteristics match thinning criteria
THIN
stand characteristics do not match thinning criteria
stand characteristics do not match t.s.i. criteria
NO TREATMENT
stand characteristics match t.s.i. criteria
T.S.I.
stand age ≥ harvest age — 10 years
area control harvest acreage for the decade has been reached
NO TREATMENT
area control harvest acreage for the decade has not been reached
HARVEST

Figure 1.—*Logic used in assigning forest inventory plots to treatment categories, Michigan, 1981-2010. The oldest stands in each forest type-site index range are processed first.*

est Inventory. In 1980, there were 947,400 acres of commercial forest land qualifying for stand conversion or restocking (table 3). Most of these areas were nonstocked (172,200 acres), or were aspen (169,400 acres), maple-birch (161,300 acres), or elm-ash-maple (112,700 acres) stands with very low basal areas per acre. Growing-stock volume on these areas averaged 248 cubic feet per acre (table 4). Most of this volume was in sawtimber-size trees. There was an additional 34 cubic feet per acre of cull material, primarily rough and rotten trees. This general information on volume per acre and distribution of area by forest type in 1980 can be applied to the stand conversion/restocking areas throughout the projection.

Decade I (1981-1990)

Treatments are identified for the first decade of the projection by using a commercial forest land base of 17.4 million acres. This area is 109,400 acres less than that reported in 1980 during Michigan's fourth Statewide forest inventory. During Decade I, no significant treatment is prescribed for 61 percent of the commercial forest land (table 5). Of the 6.8 million acres targeted for treatment, 38 percent is harvested, 34 percent is thinned, 14 percent receives t.s.i., and 14 percent undergoes stand conversion or restocking.

Harvest

- More than 2.5 million acres is targeted for harvest, 41 percent of which is found in the Northern Lower Peninsula.

- Harvest area is concentrated in the aspen (779,500 acres) and maple-birch (663,600 acres) forest types (table 6).
- The average age of a harvested stand is 98 years. Nearly 90 percent of the harvest area comes from overmature stands (stands more than 10 years past rotation age).
- Harvests for Decade I total 4.4 billion cubic feet of growing-stock and 23.4 million cubic feet of cull material (table 7).[2]
- In all Units, hardwoods account for a majority of the growing-stock volume harvested.
- The average growing-stock volume removed per acre harvested is 1,712 cubic feet; the highest average yields come from the Western Upper Peninsula (1,826 cubic feet).
- Forty-three percent of the softwood removals volume comes from hardwood forest types; the percentage is even greater in the Western Upper Peninsula and the Southern Lower Peninsula Survey Units (table 8).
- More than half of the growing-stock volume harvested comes from stands more than 100 years old (table 9).

Thinning

- More than 13 percent (2.3 million acres) of the State's commercial forest land qualifies for thinning; the Western Upper Peninsula and Northern Lower Peninsula account for the bulk of the area (table 5).
- The maple-birch forest type supplies 85 percent of the area targeted for thinning—32 percent of the maple-birch forest type has been placed in this treatment category (table 10).
- In the maple-birch forest type, stands between the ages of 21 and 80 qualify for thinning; in all other forest types, stands qualifying for thinning are less than 51 years old.
- During the decade, nearly 1.3 billion cubic feet of growing stock and 81.6 million cubic feet of cull are removed during thinning operations (table 11).
- Although harvest volume is concentrated in sawtimber trees (75 percent), thinning volume is concentrated in poletimber trees (64 percent).
- On average, 548 cubic feet of growing stock are removed per acre thinned, although the average is higher in some Units and in some forest types (table 12).
- Thinning volumes are concentrated in 41-60-year-old stands (table 13).

Timber Stand Improvement

- A total of 927,100 acres are selected for t.s.i., 732,200 in the maple-birch forest type (table 14).
- The Western Upper Peninsula and the Northern Lower Peninsula each account for more than one-third of the t.s.i. area.
- Timber stand improvement occurs in stands 1-80 years of age; younger stands are concentrated in softwood forest types and older stands are concentrated in the hardwood forest types.
- Timber stand improvement yields total 56.9 million cubic feet of growing stock and 2.9 million cubic feet of cull in Decade I (table 15).
- Growing-stock volume from t.s.i. is concentrated in hardwood species and sawtimber-size trees. However, in the Northern Lower Peninsula, softwoods account for 73 percent of the total growing-stock volume from t.s.i, and poletimber-size trees account for 51 percent of the total (table 16).
- Although t.s.i. area is concentrated in the maple-birch forest type, t.s.i. growing-stock volume is concentrated in the white spruce and white pine forest types (table 17).

Decade II
(1991-2000)

In Decade II, the commercial forest land base is projected to be 17.3 million acres, down 109,200 acres from Decade I. The area of all forest types is projected to decline, except for the red pine, white pine, northern white-cedar, and maple-birch types.

As in Decade I, no significant treatment was prescribed for 67 percent of the commercial forest land in the second decade (table 18). Thinning is the most common treatment, scheduled for 2.6 million acres between 1991 and 2000. The area qualifying for thinning increased 14 percent between Decades I and II.

More than 2.5 million acres of commercial forest land is targeted for harvest, down 1 percent from Decade I. The decline in harvest area reflects the decline in commercial forest area between decades. This decline is expected because the area control harvest acreage is recalculated at the beginning of each decade by using the projected commercial forest areas for that decade.

The greatest change in treatment between Decade I and II came in the t.s.i. category—448,600 acres qualify for t.s.i. in Decade II compared to 927,100 acres in Decade I.

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[2] *Average annual treatment volumes from the tables have been converted to treatment volumes for the decade to facilitate analysis.*

Harvest

- Harvest area is concentrated in the Northern Lower Peninsula Unit in Decade II as it was in Decade I—more than 1.0 million acres of the 2.5 million acres targeted for harvest in the State is found in the Northern Lower Peninsula.
- The aspen (760,200 acres) and maple-birch (674,300 acres) forest types continue to account for a majority of the harvest area (table 19).
- The average age of a harvested stand is 86 years, 12 years younger than in Decade I.
- Over the decade, harvest activities yield 5.3 billion cubic feet of growing stock and 267.9 million cubic feet of cull (table 20).
- Hardwoods supply the majority of the growing-stock removals volume except in the Eastern Upper Peninsula where volume of softwood removals is slightly higher than that of hardwood removals.
- The growing-stock volume per acre harvested is 2,088 cubic feet, up 22 percent from Decade I.
- Softwood growing-stock harvest volume for the decade increased 21 percent to 1.7 million cubic feet; hardwood forest types now supply 39 percent of the softwood volume compared to 43 percent in Decade I (table 21).

Thinning

- Growing-stock volume per acre harvested is highest in stands 91-140 years old (table 22).
- More than 15 percent of the State's commercial forest land is targeted for thinning—in the Upper Peninsula 18 percent of the area is in this treatment category.
- Thirty-eight percent (2.4 million acres) of the maple-birch acreage has been selected for thinning along with 25 percent (171,200 acres) of the red pine acreage (table 23).
- During the decade, nearly 1.4 billion cubic feet of growing stock and 54.2 million cubic feet of cull are removed during thinning operations (table 24).
- An average of 518 cubic feet of growing stock is removed per acre of commercial forest land thinned (table 25).
- In the maple-birch forest type, thinning occurs in stands from 21-81 years old; in all other forest types, thinning occurs only in stands less than 51 years old (table 26).

Timber Stand Improvement

- In Decade II, t.s.i. occurs on 448,600 acres of commercial forest land, down 52 percent from that recorded in Decade I—the largest percentage decrease in t.s.i. area occurred in the Western Upper Peninsula (61 percent) (table 27).
- Timber stand improvement operations yield 20.2 million cubic feet of growing stock and 0.8 million cubic feet of cull during the decade (table 28).
- Softwood species account for a majority of the t.s.i. growing-stock volume.
- For most species, t.s.i. growing-stock volume is concentrated in sawtimber trees, except for balsam fir, soft maple, and quaking aspen species (table 29).
- The area qualifying for t.s.i. remains concentrated in the maple-birch forest type; growing-stock volume is concentrated in the northern white-cedar forest type (table 30).

Decade III (2001-2010)

The area projection for Decade III sets commercial forest area for the State at 17.2 million acres, down 51,100 acres from Decade II. In each Unit, the commercial forest area declines throughout the projection period except in the Northern Lower Peninsula. The fourth Michigan Forest Inventory showed 6,708,000 acres of commercial forest land in the Northern Lower Peninsula in 1980. We projected a 10,600-acre decline in the Unit area during the first decade of the projection period, followed by a 300-acre decline in the second decade. By the final decade of the projection, State forestry experts expect a halt in the decline in commercial forest area in the Northern Lower Peninsula and an actual increase in area (we estimate a 2,000-acre increase) as a result of planting and other reclamation efforts. Statewide, the red pine, white pine, northern white-cedar, and maple-birch forest types continue to show slight increases (an average of less than 1 percent) in commercial forest areas while the areas of all other types decline.

Treatments are assigned to 5.4 million acres of commercial forest land; no significant treatment is assigned to the remaining 11.8 million acres (table 31). Thinning is prescribed for 2.6 million acres, down 36,100 from that reported in Decade II. Only the Southern Lower Peninsula showed an increase in thinning area, as the acreage in this treatment category jumped from 251,200 acres in Decade II to 347,800 in Decade III. The area harvested and thinned on commercial land declined slightly during the decade. There was a 29-percent decline in the t.s.i. area.

Harvest

- Harvest area in Decade III is 2.5 million acres, down 39,700 acres from Decade I and 13,400 acres from Decade II. An average of 15 percent of the commercial forest area is harvested in each decade.
- The average age of a harvested stand is 77 years; the youngest average harvest age occurs in the Northern Lower Peninsula (64 years). Despite a 21-percent decline in the average harvest age over the projection period, more than 62 percent of the harvest area in Decade III comes from overmature stands (table 32).
- Growing-stock yields from harvest total nearly 5.8 billion cubic feet for the decade, cull yields total nearly 282.9 million cubic feet (table 33).
- The average growing-stock volume per acre harvested is 2,289 cubic feet per acre (table 34).
- Thirty-six percent of the softwood growing-stock volume comes from hardwood forest types (table 35). Although this percentage is down from the first two decades, the total softwood volume supplied by hardwood forest types is up—from 604.4 million cubic feet in Decade I to 729.3 million cubic feet in Decade III.

Thinning

- Commercial forest area qualifying for thinning (2.6 million acres) continues to account for more than 15 percent of the commercial forest land base.
- Thirty-seven percent of the maple-birch forest type (2.4 million acres) qualifies for thinning in Decade III along with 19 percent of the red pine acreage (134,800 acres) and small portions of the oak-hickory (98,600 acres), white pine (2,900 acres), and white spruce (1,200 acres) forest type acreages (table 36).
- Thinning yields 1.6 billion cubic feet of growing stock and 51.3 million cubic feet of cull during the decade (table 37).
- The average growing-stock removals per acre thinned is 617 cubic feet per acre (table 38).
- The majority of the growing-stock thinning volume comes from maple-birch stands more than 60 years old (table 39).

Timber Stand Improvement

- The area of t.s.i. again declines between decades, down more than 29 percent from Decade II to 316,600 (table 40).
- During the decade, t.s.i. treatment opportunities yield 33.1 million cubic feet of growing-stock volume and 0.7 million cubic feet of cull (table 41).
- The average growing-stock volume removed per acre of commercial forest land undergoing t.s.i. is 104 cubic feet (tables 42, 43).

DISCUSSION

According to the assumptions and criteria outlined earlier, 17.8 million acres of Michigan's forests would qualify for treatment over the next 30 years. Between 1981 and 2010, final harvests would yield an estimated 15,426.5 million cubic feet of growing stock; thinning and t.s.i. would yield 4,240.6 million and 110 million cubic feet of growing stock, respectively. In this section we will: (1) compare our estimate of long-term timber supply to an estimate of long-term timber demand, (2) compare average annual removals in 1979 to average annual removals for the decade 1981-1990, (3) give examples of how forest managers and planners can modify the study results for a particular user or region, and (4) discuss sustainable yield in Michigan.

Long-Term Timber Supply and Demand

The predicted yields from harvest activities over the projection provide one estimate of long-term timber supply. This estimate is restricted by the assumptions and methods outlined earlier; however, given these restrictions and the management criteria specified, it is our best estimate of what is likely to happen in the future, using area control.

This estimate of long-term timber supply is of limited use without a comparison to projected long-term timber demand. The Market Analyst at the North Central Forest Experiment Station has estimated two levels of long-term timber demand for softwood and hardwood growing stock. Demand estimates show growing-stock removals increasing from 1979 levels at the annual rates shown on the next page.

	Percent change in the volume of growing-stock removals	
Years	Softwoods	Hardwoods
	High option	
1980-1984	2.5	1.3
1985-1989	4.6	2.6
1990-1994	6.2	2.9
1995-1999	4.8	2.5
2000-2004	3.6	2.3
2005-2010	3.2	2.2
	Low option	
1980-1984	(-)1.2	(-)1.0
1985-1989	1.0	1.2
1990-1994	3.6	2.7
1995-1999	4.0	2.3
2000-2004	3.1	2.0
2005-2010	2.5	1.8

These estimates of change in demand are based on predicted market response to economic forecasts.

A comparison between estimates of long-term timber supply and demand shows that growing-stock supply should exceed the high and low estimates of demand (fig. 2):

	STEMS estimate of long-term timber supply—average annual growing-stock removals		Analyst's estimate of long-term timber demand—average annual growing-stock removals	
	Harvest only	All treatments[2]	High	Low
	(Millions of cubic feet)			
Softwoods				
1981-1990	140.7	164.9	69.7	54.9
1991-2000	170.5	199.8	115.9	71.2
2001-2010	202.0	236.1	171.1	97.9
Hardwoods				
1981-1990	297.1	405.6	244.3	214.4
1991-2000	357.8	467.2	316.9	260.3
2001-2010	374.4	504.2	400.4	319.8

If the intensified management implied by our thinning and t.s.i. schedules is not achieved, we will be relying on harvest activities, alone, to supply growing-stock volume. There is a level of uncertainty implicit in these projections; however, the uncertainty surrounding our estimates of harvest areas and yields is probably less than that associated with the other treatment opportunities. If we look at potential growing-stock harvest volume (the solid line in figure 2), we find that projected demand under the high option will exceed potential harvest volume in the third decade of the projection. Relative to the high demand option, forest managers and planners should be alert to the possibility that shortages in growing-stock volume could occur early in the next century if intensified management activities, such as thinning and t.s.i., are not undertaken.

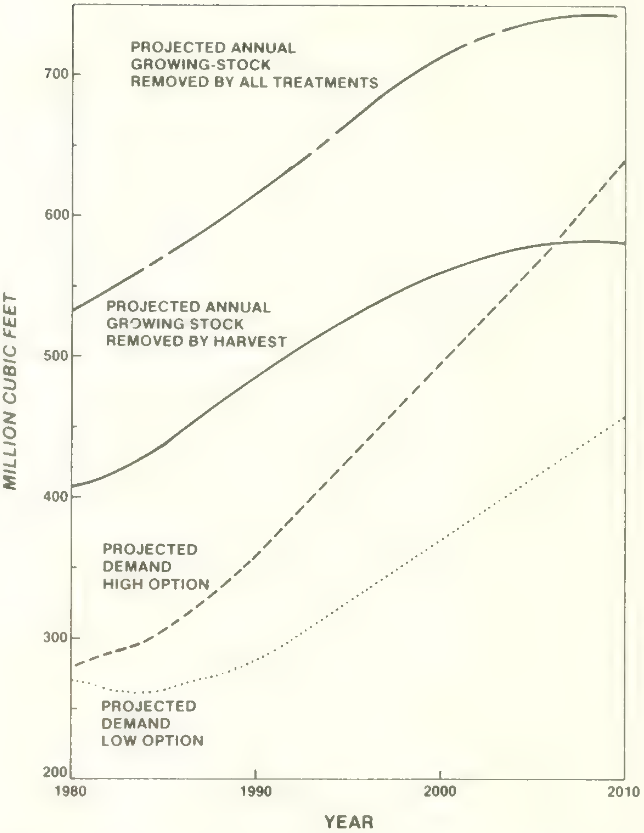

Figure 2.—*Stems projected average annual growing-stock harvest volume and low and high option demand projections, Michigan, 1980-2010.*

Average Annual Growing-Stock Removals 1979 vs 1981-1990

In the section on long-term timber supply and demand, we limited discussion to total softwood and total hardwood volumes for the entire State. This constraint was necessary because of the methods used to derive long-term timber demand. However, by limiting our analysis to only two species groups and the State as a whole, we may have masked important findings or considerations. For this reason it is useful to compare 1979 average annual growing-stock removals from the fourth Michigan Forest Inventory to average annual growing-stock removals for the decade 1981-1990 by species and Forest Survey Unit (table 44). This comparison shows that in 1979 growing-stock removals of several species already exceed average annual removals for Decade I and that opportunities exist for increasing average annual removals of other species.

Softwood Highlights

In 1979 jack pine accounted for 29 percent of the softwood growing-stock removal—in the Northern Lower Peninsula the species accounted for 52 percent of the total (Raile and Smith 1983). However, recent jack pine harvests may be exceeding desirable, or sustainable levels in some areas:

	Jack pine average annual growing-stock removals		
	Reported	STEMS estimate 1981-1990	
Survey unit	**1979**	**Harvest only**	**All treatments[3]**
		(Thousand cubic feet)	
Eastern Upper Peninsula	5,230	4,300	4,419
Western Upper Peninsula	2,889	2,197	2,351
Northern Lower Peninsula	7,999	8,457	9,958
Southern Lower Peninsula	74	346	366
State totals	16,192	15,300	17,094

In the Upper Peninsula more jack pine was cut in 1979 than is estimated to be available annually in Decade I for all treatments. In the Northern Lower Peninsula removals are approaching Decade I levels. Forest managers and planners will want to keep close track of what is happening to the jack pine resource in their areas to avoid possible problems in the future.

Red pine has long been a species favored by forest managers in the Lake States. Although disease problems have recently dampened some of the enthusiasm foresters have had for the species, inventory data indicate that red pine accounts for more than 13 percent of the softwood growing-stock inventory and 14 percent of the removals (Raile and Smith 1983). Our analysis shows that red pine removals can increase substantially in some areas while approaching long-term supply levels in other areas:

	Red pine average annual growing-stock removals		
	Reported	STEMS estimate 1981-1990	
Survey unit	**1979**	**Harvest only**	**All treatments[3]**
		(Thousand cubic feet)	
Eastern Upper Peninsula	1,422	3,497	4,443
Western Upper Peninsula	1,945	2,011	2,694
Northern Lower Peninsula	3,105	9,797	18,754
Southern Lower Peninsula	1,326	811	1,498
State totals	7,798	16,116	27,389

When 1979 average annual removals for balsam fir are compared to 1981-1990 average annual removals, it appears that there are opportunities for greatly increasing harvest levels. However, the STEMS projection system does not adequately account for catastrophic mortality, such as that caused by spruce budworm. For this reason projected balsam fir growing-stock removals may be overly optimistic for all treatments and decades.

Hardwood Highlights

In recent years the expansion of existing timber industries and establishment of new timber industries have relied, for the most part, on the State's aspen resource. In 1979, bigtooth and quaking aspen accounted for 38 percent of hardwood growing-stock removals and 30 percent of the total growing-stock removals (Raile and Smith 1983). Aspen growing-stock removals throughout the State should be monitored as current annual removals approach long-term supply:

	Aspen average annual growing-stock removals		
	Reported	STEMS estimate 1981-1990	
Survey unit	**1979**	**Harvest only**	**All treatments[3]**
		(Thousand cubic feet)	
Eastern Upper Peninsula	10,167	12,224	13,834
Western Upper Peninsula	26,302	17,797	21,587
Northern Lower Peninsula	45,229	43,926	47,311
Southern Lower Peninsula	1,497	4,204	4,865
State total	83,195	78,151	87,597

For some products, paper birch may be substituted for aspen. Throughout the State, paper birch growing-stock removals may be at least doubled before they reach long-term supply levels:

	Paper birch average annual growing-stock removals		
	Reported	STEMS estimate 1981-1990	
Survey unit	**1979**	**Harvest only**	**All treatments[3]**
		(Thousand cubic feet)	
Eastern Upper Peninsula	2,471	5,875	6,747
Western Upper Peninsula	2,574	6,672	7,526
Northern Lower Peninsula	2,579	7,198	8,503
Southern Lower Peninsula	110	233	269
State total	7,734	19,978	23,045

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[3] *Includes harvest, thinning, and t.s.i.*

Fine-Tuning Study Assumptions to Reflect Local Resource Conditions

The treatments specified in this study may not be carried out for many reasons—timber management may be incompatible with owner objectives, markets may not exist for all of the material removed during treatments, physical features may limit the operability of certain stands, or administrative regulation may limit management options.

Forest managers and planners can use their knowledge of local conditions to modify this study's assumptions and criteria to the economics of management or to a particular user or region. In addition, statewide forest inventories provide data that may be used to strengthen the assumptions and criteria used here.

For example, road building costs can be a crucial factor in deciding whether to carry out a management activity (Milton 1981). According to the data collected during the fourth Michigan Forest Inventory, nearly 85 percent of the commercial forest land in the State is within 1 mile (linear air distance) of a maintained road and 38 percent of the commercial forest area is within one-fourth mile of a maintained road. If we look at the plots selected for treatment over the projection period, we find that these areas are distributed among distance-to-road classes in roughly the same proportion as the State's commercial forest area (Raile and Smith 1983):

	Distance to road (in miles)		
	0-¼	½-1	more than 1
	(Percent of area)		
Harvest area	36.2	45.9	17.9
Thinning area	39.2	48.5	12.3
T.s.i. area	39.5	48.1	12.4
Stand conversion or restocking area	42.1	42.9	15.0
Total commercial forest area (1980)	38.8	45.8	15.4

If the data user feels that distance to road is a factor that should not be overlooked when using the findings of this study, standard forest inventory data can be used to adjust the findings.

The stand area available for treatment can affect management decisions, particularly when the efficiency of the equipment being used is affected by economies of scale (Cubbage 1981). It appears that over the 30-year projection period, a disproportionate share of the stands qualifying for treatment occur as small blocks of land. Of the area qualifying for treatment over the projection period, nearly one-third occurs in stands less than 10 acres. Data from the 1980 Michigan Forest Inventory show that less than 10 percent of the total commercial forest area in the State is in stands less than 10 acres (Raile and Smith 1983). One explanation for this discrepancy is that currently, stands extending over large areas are being better managed than stands covering smaller areas. National forest and forest industry commercial forest holdings are concentrated in stands more than 80 acres. If we can assume that in these two ownerships forest management is practiced more often and at a higher level than in other ownerships, then it is reasonable to assume that these forests would require less management over the projection period than forests in other ownerships. Also, nonindustrial private owners who have stands covering large areas are probably more likely to be aware of and practice forest management activities. If stand area is an important input to a forest management decision, then the data user can assume that our treatment areas are distributed among stand area classes as follows:

Stand area class (acres)	Percent of treatment area
1-4	14.6
5-9	16.9
10-19	22.1
20-39	21.8
40-79	6.0
80-159	4.3
160-319	12.5
320+	1.8

Site quality is yet another factor that influences management decisions. For most management activities, the return per dollar invested will be greater from higher quality sites than from lower quality sites. The area of commercial forest land qualifying for treatment is distributed among site index classses in roughly the same proportion as the State's commercial forest area (Raile and Smith 1983):

	Site index		
	Less than 41	41-70	More than 70
		(Percent of area)	
Harvest area	11.3	60.3	28.4
Thinning area	0.7	57.4	41.9
T.s.i. area	9.4	65.4	25.2
Stand conversion of restocking area	16.0	67.7	16.3
Total commercial forest area (1980)	11.4	67.2	21.4

For all treatments the majority of the commercial forest area has a site index of 41-70; more area is on sites with a site index greater than 70 than where the site index is less than 40.

Sustained Yield for Michigan

By the year 2010, Michigan's average annual growing stock removals will be nearly 580 million cubic feet. Although growing-stock harvest volume may be approaching sustainable yield, opportunities exist for further increasing the State's wood-fiber potential.

Empirical yield estimates from stands currently at rotation age indicate that sustainable growing-stock volumes from the area control harvest acreage would total 373 million cubic feet annually. However, if we use estimates of yields from published yield tables for well-stocked stands, a potential growing-stock harvest volume of 580 million cubic feet could be achieved for the area control acreage. Thus, under area control, the sustained growing-stock yields from harvest operations in Michigan's forests should fall between 373 million cubic feet and 580 million cubic feet per year. The lower figure indicates minimal management activity and the higher figure indicates more intense management.

Growing-stock volumes will also be available from thinning and t.s.i. operations. In Decade III, growing-stock removals from these activities totaled 164 million cubic feet. Estimates of the sustainable thinning and t.s.i. contributions to growing-stock harvest volume under area control fall between 93 million cubic feet and 145 million cubic feet annually. Thus, the total annual sustainable growing-stock yield from all harvest, thinning, and t.s.i. management opportunities on stocked stands would fall between 466 million cubic feet and 725 million cubic feet annually under area control.

The volumes shown in this report only account for the wood fiber in the boles of growing-stock trees. Research indicates that the volume in the tops and limbs of growing-stock trees is equal to approximately 45 percent of the bole volume. Therefore, utilizing tops and limbs could increase total yields to between 676 million cubic feet and 1,051 million cubic feet of wood fiber annually.

Another major opportunity lies in more complete utilization of nonstocked and poorly stocked commercial forest land. If we assume an average rotation age of 60 years for Michigan's 947,400 acres of nonstocked and poorly stocked commercial forest land, an additional 15,790 acres could be placed on rotation annually. The yields from the harvest of growing-stock boles, tops, and limbs on this area could total between 35 million cubic feet and 52 million cubic feet annually.

Finally, harvest, thinning, and t.s.i. activities are not restricted to growing-stock trees. Non-growing-stock material (shortlog and rough and rotten trees) currently accounts for roughly 5 percent of all harvest volume. Adjustments for non-growing-stock removals, including tops and limbs, would increase our estimate of total sustainable yield to between 710 million cubic feet and 1,104 million cubic feet of fiber annually.

This final estimate of sustained yield does not take into account the potential for increased yield realized by shifting marginal stands to more productive species. It does reflect assumptions outlined earlier.

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APPENDIX

TREE SPECIES GROUPS[4]

Softwoods	
Eastern white pine	*Pinus strobus*
Red pine	*Pinus resinosa*
Jack pine	*Pinus banksiana*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea*
Eastern hemlock	*Tsuga canadensis*
Tamarack	*Larix laricina*
Northern white-cedar	*Thuja occidentalis*
Other softwoods	
Eastern redcedar	*Juniperus virginiana*
Norway spruce	*Picea abies*
Austrian pine	*Pinus nigra*
Scotch pine	*Pinus sylvestris*
Hardwoods	
White oaks	
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Bur oak	*Quercus macrocarpa*
Chestnut oak	*Quercus prinus*
Select red oak	
Northern red oak	*Quercus rubra*
Other red oaks	
Scarlet oak	*Quercus coccinea*
Northern pin oak	*Quercus ellipsoidalis*
Black oak	*Quercus velutina*
Hickories	
Shagbark hickory	*Carya ovata*
Bitternut hickory	*Carya cordiformis*
Yellow birch	*Betula alleghaniensis*
Hard maple	
Sugar maple	*Acer saccharum*
Soft maples	
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
American beech	*Fagus grandifolia*
Ashes	
White ash	*Fraxinus americana*
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
Balsam poplar	*Populus balsamifera*
Eastern cottonwood	*Populus deltoides*
Aspens	
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Basswood	*Tilia americana*
Black cherry	*Prunus serotina*
Elms	
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*
Rock elm	*Ulmus thomasii*
Paper birch	*Betula papyrifera*
Other hardwoods	
Black walnut	*Juglans nigra*
Butternut	*Juglans cinerea*
Honeylocust	*Gleditsia triacanthos*
Sassafras	*Sassafras albidum*
River birch	*Betula nigra*
American chestnut	*Castanea dentata*
Sycamore	*Platanus occidentalis*
Black tupelo	*Nyssa sylvatica* var. *sylvatica*
Red mulberry	*Morus rubra*
Black willow	*Salix nigra*
Noncommercial species	
Eastern hophornbeam	*Ostrya virginiana*
Peachleaf willow	*Salix amygdaloides*
American hornbeam	*Carpinus caroliniana*
Hawthorn	*Crataegus spp.*
Striped maple	*Acer pensylvanicum*
Mountain-ash	*Sorbus spp.*
Pin cherry	*Prunus pensylvanica*
Chokecherry	*Prunus virginia*

METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT

1 acre = 4,046.86 square meters or 0.405 hectare
1,000 acres = 405 hectares
1 cubic foot = 0.0283 cubic meter
1 foot = 30.48 centimeters or 0.3048 meter
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter
1 pound = 0.454 kilogram
1 ton = 0.907 metric ton

DEFINITION OF TERMS

Acceptable trees.—Growing-stock trees of commercial species that meet specified standards of size and quality but do not qualify as desirable trees.

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

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[4] *The common and scientific names are based on: Little, Elbert L. Check list of native and naturalized trees of the United States. Agric. Handb. 541. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 1979. 375 p.*

Commercial forest land.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as commerical forest land have the capability of producing in excess of 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)

Desirable trees.—Growing-stock trees having no serious defects in quality limiting present or prospective use, and of relatively high vigor, and containing no pathogens that may result in death or serious deterioration before rotation age. These are trees that would be favored by forest managers in silvicultural operations.

Forest type.—A classification of forest land based upon the species forming a plurality of live tree stocking. Major forest types in Michigan are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include balsam fir, aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, beech, yellow-poplar, elm, and maple.)

Elm-ash-maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Maple-birch.—Forests in which sugar maple, basswood, American beech, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Exotic.—Forests in which species not native to Michigan comprise a plurality of the stocking. (Mostly scotch pine plantations.)

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing stock trees 5.0 inches d.b.h. and over, from a 1-foot stump to a minimum 4.0 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to cords by dividing by 79 cubic feet per solid wood cord.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Maintained road.—Any road, hard-topped or other surfaces, that is plowed or graded at least once a year. Includes rights-of-way that are cut or treated to limit herbaceous growth.

Net volume.—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Ownership.—Property owned by one owner, regardless of the number of parcels in a specified area.

Poletimber trees.—Growing-stock trees of commercial species at least 5.0 inches d.b.h., but smaller than sawtimber size.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting Regional specifications for freedom from defect. Softwoods must be at least 9.0 inches d.b.h. Hardwoods must be at least 11.0 inches d.b.h.

Short-log (rough tree).—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Site index.—An expression of forest site quality based on the height of a free-growing dominant or codominant tree of a representative species in the forest type at age 50.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.—The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

State land.—Land owned by States, or land leased to these governmental units for 50 years or more.

Stocking.—The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard.

A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h.

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Table 1.--Management criteria, Michigan, 1981-2010

Forest type	Rotation age	Basal area for thinning	Post thinning basal area	Timber stand improvement[1]
	years	square feet		
Jack pine	50	no		yes
Red pine	60	140	90	yes
White pine	80	140	90	yes
White spruce	60	STEMS[1]		yes
Black spruce	70	no		no
Balsam fir	50	STEMS[1]		yes
Tamarack	60	no		no
Northern white-cedar	80	no		yes
Oak-hickory	70	STEMS[1]		yes
Elm-ash-maple	70	no		no
Maple-birch	90	STEMS[1]		yes
Aspen	40	no		no
Paper birch	50	no		no
Exotic	60	no		no

[1] Used management criteria built in to the Stand and Tree Evaluating and Modeling System (STEMS). See Brand, Gary J. 1981. Simulating Timber Management in Lake States Forests. USDA Forest Service, North Central Forest Experiment Station, GTR NC-69, 25 p.

Table 2.--Area of commercial forest land, 1966[1/] 1980, and projections of commercial forest area, 1981-2010, by forest type, Michigan[2/]

(In thousand acres)

Forest type	1966	1980	Projections 1985	Projections 1995	Projections 2005
Jack pine	883.5	836.7	831.1	826.0	823.5
Red pine	594.8	656.0	677.4	693.9	701.9
White pine	147.9	214.2	217.2	221.3	224.7
White spruce	172.7	100.1	91.3	85.6	83.2
Black spruce	421.1	520.7	520.3	520.1	520.0
Balsam fir	899.2	635.3	605.9	578.4	565.8
Tamarack	162.8	114.8	108.6	102.5	99.6
Northern white-cedar	1,160.5	1,173.6	1,187.7	1,203.0	1,211.0
Oak-hickory	2,273.2	1,773.7	1,734.2	1,690.8	1,655.6
Elm-ash-maple	1,781.1	1,326.3	1,260.1	1,198.1	1,168.5
Maple-birch	5,203.2	6,098.2	6,196.9	6,293.1	6,352.5
Aspen	4,128.8	3,406.7	3,328.7	3,248.9	3,210.2
Paper birch	403.9	374.8	365.9	357.8	354.0
Exotic	118.2	86.2	89.6	87.3	86.0
Nonstocked	538.4	172.3	165.2	164.1	163.3
All types	18,889.3	17,489.5	17,380.1	17,270.9	17,219.8

[1/] Area has been adjusted from those published after the 1966 survey to conform to 1980 areas because of changes in survey procedures and definitions.

[2/] Table may not add to totals due to rounding.

Table 3.--Commercial forest area qualifying for stand conversion or restocking by forest type and Forest Survey Unit, Michigan, 1980[1/]

(In thousand acres)

Forest type	All units	Forest Survey Unit Eastern Upper Peninsula	Western Upper Peninsula	Northern Lower Peninsula	Southern Lower Peninsula
Jack pine	65.6	27.1	2.9	35.6	--
Red pine	37.9	10.7	--	27.2	--
White pine	16.9	6.3	1.7	4.0	4.9
White spruce	7.9	4.9	--	3.0	--
Black spruce	56.0	35.0	14.8	6.2	--
Balsam fir	25.7	4.1	18.6	3.0	--
Tamarack	11.4	4.4	2.1	4.9	--
Northern white-cedar	17.3	9.5	--	4.5	3.3
Oak-hickory	78.1	1.6	--	46.6	29.9
Elm-ash-maple	112.7	8.3	5.5	48.4	50.5
Maple-birch	161.3	12.7	2.6	67.4	78.6
Aspen	169.4	39.8	32.8	86.6	10.2
Paper birch	11.5	3.0	4.2	4.3	--
Exotic	3.5	--	--	3.5	--
Nonstocked	172.2	40.2	28.7	63.2	40.1
All types	947.4	207.6	113.9	408.4	217.5

[1/] Table may not add to totals due to rounding.

Table 4.--Growing-stock volume on stands selected for stand conversion or restocking by species group, tree class, and Forest Survey Unit, Michigan, 1980[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
			ALL UNITS			
SOFTWOODS						
Jack pine	18,021	9,088	8,933	996	90	906
Red pine	13,633	2,909	10,724	94	60	34
White pine	9,506	1,009	8,497	1,367	--	1,367
White spruce	3,572	1,273	2,299	720	--	720
Black spruce	9,447	5,089	4,358	81	--	81
Balsam fir	4,924	2,637	2,287	81	81	--
Hemlock	--	--	--	20	--	20
Tamarack	6,925	3,830	3,095	415	60	355
Northern white-cedar	4,103	2,047	2,056	610	--	610
Other softwoods	2,540	2,030	510	826	200	626
Total	72,671	29,912	42,759	5,210	491	4,719
HARDWOODS						
White oak	10,060	3,680	6,380	410	150	260
Select red oak	16,718	3,217	13,501	1,320	730	590
Other red oak	4,420	1,410	3,010	350	100	250
Hickory	1,220	210	1,010	--	--	--
Basswood	3,020	440	2,580	--	--	--
Beech	610	400	210	500	340	160
Yellow birch	100	--	100	50	--	50
Hard maple	7,770	2,780	4,990	4,090	1,048	3,042
Soft maple	26,868	8,418	18,450	4,548	347	4,201
Elm	7,833	4,573	3,260	2,224	178	2,046
Ash	12,665	7,947	4,718	1,128	--	1,128
Cottonwood	1,870	790	1,080	--	--	--
Balsam poplar	8,072	1,878	6,194	415	110	305
Bigtooth aspen	4,734	2,624	2,110	341	--	341
Quaking aspen	30,092	12,934	17,158	5,479	1,038	4,441
Paper birch	6,798	3,707	3,091	1,046	80	966
Black cherry	9,452	4,348	5,104	4,200	--	4,200
Other hardwoods	10,050	390	9,660	790	--	790
Total	162,352	59,746	102,606	26,890	4,121	22,770
All species	235,023	89,658	145,365	32,101	4,612	27,489
			EASTERN UPPER PENINSULA			
SOFTWOODS						
Jack pine	8,531	4,098	4,433	347	90	257
Red pine	4,392	795	3,597	94	60	34
White pine	4,750	503	4,247	1,127	--	1,127
White spruce	2,032	763	1,269	--	--	--
Black spruce	7,337	3,099	4,238	41	--	41
Balsam fir	1,454	867	587	--	--	--
Tamarack	2,545	1,300	1,245	50	--	50
Northern white-cedar	1,993	787	1,206	358	--	358
Total	33,034	12,212	20,822	2,017	150	1,867
HARDWOODS						
Select red oak	900	--	900	--	--	--
Basswood	150	--	150	--	--	--
Yellow birch	--	--	--	50	--	50
Hard maple	2,600	1,010	1,590	110	--	110
Soft maple	2,443	1,436	1,007	931	--	931
Elm	390	130	260	156	--	156
Ash	1,360	1,130	230	77	--	77
Balsam poplar	1,802	738	1,064	145	110	35
Bigtooth aspen	764	364	400	41	--	41
Quaking aspen	6,215	3,377	2,838	720	--	720
Paper birch	1,736	725	1,011	6	--	6
Black cherry	100	100	--	--	--	--
Total	18,460	9,010	9,450	2,236	110	2,126
All species	51,494	21,222	30,272	4,253	260	3,993

(Table 4 continued on next page)

(Table 4 continued)

Species group	Tree class					
	Growing stock			Cull		
	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2/]
WESTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	1,076	736	340	--	--	--
Red pine	1,720	710	1,010	--	--	--
White pine	986	56	930	170	--	170
White spruce	1,300	270	1,030	720	--	720
Black spruce	1,590	1,590	--	40	--	40
Balsam fir	3,000	1,500	1,500	--	--	--
Hemlock	--	--	--	20	--	20
Tamarack	770	390	380	60	--	60
Northern white-cedar	450	370	80	--	--	--
Total	10,892	5,622	5,270	1,010	--	1,010
HARDWOODS						
Select red oak	730	350	380	--	--	--
Yellow birch	100	--	100	--	--	--
Hard maple	380	270	110	190	--	190
Soft maple	790	430	360	280	90	190
Elm	440	90	350	100	100	--
Ash	260	--	260	90	--	90
Balsam poplar	2,000	190	1,810	--	--	--
Quaking aspen	5,957	2,637	3,320	2,478	430	2,048
Paper birch	1,442	822	620	200	80	120
Black cherry	100	100	--	230	--	230
Total	12,199	4,889	7,310	3,568	700	2,868
All species	23,091	10,511	12,580	4,578	700	3,878
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	8,414	4,254	4,160	649	--	649
Red pine	6,331	1,404	4,927	--	--	--
White pine	3,480	450	3,030	70	--	70
White spruce	240	240	--	--	--	--
Black spruce	520	400	120	--	--	--
Balsam fir	470	270	200	81	81	--
Tamarack	2,610	1,720	890	215	60	155
Northern white-cedar	1,660	890	770	252	--	252
Other softwoods	2,150	2,030	120	46	--	46
Total	25,875	11,658	14,217	1,313	141	1,172
HARDWOODS						
White oak	6,450	3,680	2,770	150	150	--
Select red oak	13,428	2,867	10,561	890	300	590
Other red oak	2,410	710	1,700	180	100	80
Basswood	1,060	--	1,060	--	--	--
Beech	610	400	210	160	--	160
Hard maple	2,460	1,130	1,330	2,771	468	2,303
Soft maple	15,575	4,882	10,693	2,767	257	2,510
Elm	1470	950	520	441	--	441
Ash	5,615	3,837	1,778	231	--	231
Balsam poplar	2,100	480	1,620	130	--	130
Bigtooth aspen	3,740	2,030	1,710	300	--	300
Quaking aspen	16,950	6,340	10,610	2,281	608	1,673
Paper birch	2,920	1,610	1,310	720	--	720
Black cherry	4,222	2,348	1,874	2,140	--	2,140
Other hardwoods	740	--	740	290	--	290
Total	79,750	31,264	48,486	13,451	1,883	11,568
All species	105,625	42,922	62,703	14,764	2,024	12,740

(Table 4 continued on next page)

(Table 4 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Red pine	1,190	--	1,190	--	--	--
White pine	290	--	290	--	--	--
Tamarack	1,000	420	580	90	--	90
Other softwoods	390	--	390	780	200	580
Total	2,870	420	2,450	870	200	670
HARDWOODS						
White oak	3,610	--	3,610	260	--	260
Select red oak	1,660	--	1,660	430	430	--
Other red oak	2,010	700	1,310	170	--	170
Hickory	1,220	210	1,010	--	--	--
Basswood	1,810	440	1,370	--	--	--
Beech	--	--	--	340	340	--
Hard maple	2,330	370	1,960	1,019	580	439
Soft maple	8,060	1,670	6,390	570	--	570
Elm	5,533	3,403	2,130	1,527	78	1,449
Ash	5,430	2,980	2,450	730	--	730
Cottonwood	1,870	790	1,080	--	--	--
Balsam poplar	2,170	470	1,700	140	--	140
Bigtooth aspen	230	230	--	--	--	--
Quaking aspen	970	580	390	--	--	--
Paper birch	700	550	150	120	--	120
Black cherry	5,030	1,800	3,230	1,830	--	1,830
Other hardwoods	9,310	390	8,920	500	0	500
Total	51,943	14,583	37,360	7,635	1,428	6,208
All species	54,813	15,003	39,810	8,506	1,628	6,878

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 5.--Commercial forest area qualifying for treatment and average annual yields of growing stock from each treatment by treatment category and Survey Unit, Michigan, 1981-1990[1]

COMMERCIAL FOREST AREA

		Forest Survey Unit			
Treatment	All units	Eastern Upper Peninsula	Western Upper Peninsula	Northern Lower Peninsula	Southern Lower Peninsula
		In thousand acres			
Harvest	2,557.3	556.3	650.0	1,050.3	300.7
Thinning	2,318.4	442.6	849.4	795.4	231.0
Timber stand improvement	927.1	176.1	314.1	327.3	109.6
Stand conversion or restocking	947.4	207.6	113.9	408.4	217.5
No treatment	10,629.9	2,378.0	2,557.9	4,116.0	1,578.0
Total	17,380.1	3,760.6	4,485.3	6,697.4	2,436.8
AVERAGE ANNUAL YIELDS OF GROWING STOCK					
		In thousand cubic feet			
Harvest	437,871	89,821	118,702	175,239	54,109
Thinning	126,944	23,885	46,004	48,424	8,631
Timber stand improvement	5,687	2,110	1,679	1,585	313
Total	570,502	115,816	166,385	225,248	63,053

[1] Tables may not add to totals due to rounding.

Table 6.--Commercial forest area qualifying for harvest by forest type, stand-age class, and Forest Survey Unit, Michigan, 1981-1990[1/]

(In thousand acres)

ALL UNITS

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	149.8	--	--	--	54.6	36.7	34.7	14.6	4.4	2.3	2.5	--
Red pine	105.9	--	--	27.9	7.5	17.6	14.7	10.9	7.5	18.2	1.5	--
White pine	25.0	--	--	--	--	--	2.2	--	2.1	3.4	12.8	4.7
White spruce	12.8	--	--	--	--	--	--	2.4	--	8.2	--	2.2
Black spruce	65.4	--	--	--	4.3	14.6	9.4	3.2	7.5	13.3	7.3	5.8
Balsam fir	116.0	--	--	--	9.6	12.2	22.4	17.8	14.6	23.6	11.0	4.8
Tamarack	14.7	--	--	--	--	2.5	1.5	1.5	3.2	3.7	--	2.3
Northern white-cedar	145.2	--	--	--	--	--	0.7	--	--	23.8	63.3	57.3
Oak-hickory	235.2	--	--	--	--	--	--	--	49.9	129.7	44.3	11.3
Elm-ash-maple	159.9	--	--	--	--	--	--	--	19.9	83.4	40.7	15.9
Maple-birch	663.6	--	--	--	--	--	--	--	88.7	218.4	271.7	84.9
Aspen	779.5	--	--	6.5	175.5	228.3	148.7	94.7	66.9	50.2	8.7	--
Paper birch	70.2	--	1.2	--	--	16.3	23.1	8.1	11.9	3.0	4.9	1.6
Exotic	14.1	--	4.8	2.2	7.1	--	--	--	--	--	--	--
All types	2,557.3	--	6.0	36.7	258.4	328.1	257.6	153.3	276.5	581.2	468.7	190.8
EASTERN UPPER PENINSULA												
Jack pine	38.2	--	--	--	18.3	11.2	5.7	3.1	--	--	--	--
Red pine	22.9	--	--	1.1	3.1	6.0	6.2	1.5	1.6	3.4	--	--
White pine	8.0	--	--	--	--	--	--	--	--	0.3	4.6	3.1
White spruce	3.9	--	--	--	--	--	--	2.4	--	1.5	--	--
Black spruce	34.8	--	--	--	4.3	14.6	4.7	3.2	4.7	1.6	--	1.8
Balsam fir	39.9	--	--	--	9.6	12.2	5.9	1.4	1.5	6.3	3.0	--
Tamarack	6.0	--	--	--	--	--	1.5	1.5	1.6	1.4	--	--
Northern white-cedar	74.7	--	--	--	--	--	--	--	--	14.3	35.2	25.2
Oak-hickory	2.5	--	--	--	--	--	--	--	0.9	--	1.6	--
Elm-ash-maple	23.9	--	--	--	--	--	--	--	--	13.8	7.0	3.0
Maple-birch	126.6	--	--	--	--	--	--	--	--	33.3	67.4	25.9
Aspen	153.6	--	--	--	52.2	48.4	12.3	12.0	20.1	8.5	--	--
Paper birch	21.5	--	--	--	--	7.7	7.6	--	3.1	3.0	--	--
All types	556.3	--	--	1.1	87.4	100.1	43.9	25.1	33.5	87.6	113.7	58.9

(Table 6 continued on next page)

(Table 6 continued)

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
WESTERN UPPER PENINSULA												
Jack pine	15.8	--	--	--	4.5	4.7	3.1	1.7	1.7	--	--	--
Red pine	9.6	--	--	--	--	--	--	--	1.5	6.5	1.5	--
White pine	5.5	--	--	--	--	--	--	--	--	0.6	3.3	1.6
White spruce	6.7	--	--	--	--	--	--	--	--	6.7	--	--
Black spruce	27.5	--	--	--	--	--	1.7	--	2.8	11.7	7.3	4.0
Balsam fir	68.5	--	--	--	--	--	16.5	16.1	13.1	15.0	2.9	4.8
Tamarack	5.2	--	--	--	--	1.3	--	--	1.6	--	--	2.3
Northern white-cedar	25.8	--	--	--	--	--	--	--	--	--	11.2	14.5
Oak-hickory	2.6	--	--	--	--	--	--	--	--	1.0	1.6	--
Elm-ash-maple	22.0	--	--	--	--	--	--	--	--	--	9.1	12.9
Maple-birch	266.1	--	--	--	--	--	--	--	--	41.6	165.6	59.0
Aspen	166.8	--	--	--	32.6	46.8	50.2	24.5	5.1	7.6	--	--
Paper birch	27.9	--	--	--	--	--	6.7	8.1	6.6	--	4.9	1.6
All types	650.0	--	--	--	37.1	52.8	78.2	50.4	32.4	90.7	207.5	100.8
NORTHERN LOWER PENINSULA												
Jack pine	93.3	--	--	--	31.8	18.2	26.0	9.9	2.7	2.3	2.5	--
Red pine	68.8	--	--	22.2	4.4	11.7	8.5	9.4	4.4	8.2	--	--
White pine	9.4	--	--	--	--	--	--	--	2.1	2.5	4.9	--
White spruce	2.2	--	--	--	--	--	--	--	--	--	--	2.2
Black spruce	3.1	--	--	--	--	--	3.0	--	--	--	--	--
Balsam fir	7.6	--	--	--	--	--	--	0.2	--	2.3	5.1	--
Tamarack	3.4	--	--	--	--	1.2	--	--	--	2.3	--	--
Northern white-cedar	43.9	--	--	--	--	--	--	--	--	9.3	16.9	17.6
Oak-hickory	141.4	--	--	--	--	--	--	--	49.0	72.4	17.6	2.4
Elm-ash-maple	46.8	--	--	--	--	--	--	--	7.7	23.0	16.1	--
Maple-birch	181.0	--	--	--	--	--	--	--	74.6	86.5	19.9	--
Aspen	420.9	--	--	--	79.8	117.1	81.4	58.2	41.7	34.0	8.7	--
Paper birch	19.6	--	--	--	--	8.5	8.7	0.1	2.3	--	--	--
Exotic	9.0	--	4.5	2.2	2.2	--	--	--	--	--	--	--
All types	1,050.3	--	4.5	24.4	118.2	156.7	127.6	77.8	184.4	242.8	91.7	22.2
SOUTHERN LOWER PENINSULA												
Jack pine	2.5	--	--	--	--	2.5	--	--	--	--	--	--
Red pine	4.6	--	--	4.6	--	--	--	--	--	--	--	--
White pine	2.2	--	--	--	--	--	2.2	--	--	--	--	--
Northern white-cedar	0.9	--	--	--	--	--	0.7	--	--	0.2	--	--
Oak-hickory	88.7	--	--	--	--	--	--	--	--	56.3	23.5	8.9
Elm-ash-maple	67.3	--	--	--	--	--	--	--	12.2	46.6	8.5	--
Maple-birch	90.0	--	--	--	--	--	--	--	14.1	57.0	18.8	--
Aspen	38.3	--	--	6.5	10.9	15.9	4.9	--	--	--	--	--
Paper birch	1.2	--	1.2	--	--	--	--	--	--	--	--	--
Exotic	5.1	--	0.3	--	4.8	--	--	--	--	--	--	--
All types	300.7	--	1.5	11.2	15.8	18.4	7.8	--	26.3	160.1	50.8	8.9

[1] Tables may not add to totals due to rounding.

Table 7.--Average annual yields from harvest by species group, tree class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
ALL UNITS						
SOFTWOODS						
Jack pine	15,300	6,377	8,923	280	56	224
Red pine	16,116	2,439	13,677	45	23	22
White pine	20,208	1,377	18,831	157	89	68
White spruce	10,721	2,045	8,676	83	38	45
Black spruce	5,503	4,160	1,343	44	4	40
Balsam fir	19,119	11,578	7,541	208	44	164
Hemlock	14,573	1,413	13,160	623	213	410
Tamarack	1,458	659	799	53	--	53
Northern white-cedar	36,230	13,855	22,375	3,952	955	2,997
Other softwoods	1,513	670	843	99	--	99
Total	140,741	44,573	96,168	5,544	1,422	4,122
HARDWOODS						
White oak	11,761	1,850	9,911	413	92	321
Select red oak	28,859	2,806	26,053	1,050	343	707
Other red oak	4,099	196	3,903	192	64	128
Hickory	1,804	265	1,539	--	--	--
Basswood	8,787	1,553	7,234	356	44	312
Beech	8,459	1,083	7,376	1,312	307	1,005
Yellow birch	10,154	1,329	8,825	1,325	370	955
Hard maple	46,786	10,412	36,374	2,617	696	1,921
Soft maple	45,197	13,921	31,276	2,571	552	2,019
Elm	3,329	1,079	2,250	87	12	75
Ash	12,650	4,055	8,595	380	41	339
Cottonwood	2,390	19	2,371	15	--	15
Balsam poplar	8,946	897	8,049	369	54	315
Bigtooth aspen	30,512	6,131	24,381	1,193	104	1,089
Quaking aspen	47,639	9,338	38,301	4,071	604	3,467
Paper birch	19,978	8,103	11,875	1,240	243	997
Black cherry	3,789	1,240	2,549	344	148	196
Other hardwoods	1,991	332	1,659	304	4	300
Total	297,130	64,609	232,521	17,839	3,678	14,161
All species	437,871	109,182	328,689	23,383	5,100	18,283
EASTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	4,300	1,838	2,462	78	7	71
Red pine	3,497	258	3,239	--	--	--
White pine	4,819	294	4,525	58	33	25
White spruce	2,917	531	2,386	27	21	6
Black spruce	3,364	2,838	526	37	4	33
Balsam fir	6,365	4,369	1,996	69	14	55
Hemlock	3,909	350	3,559	221	79	142
Tamarack	583	373	210	--	--	--
Northern white-cedar	14,709	6,203	8,506	1,439	347	1,092
Total	44,463	17,054	27,409	1,929	505	1,424
HARDWOODS						
Select red oak	374	47	327	25	--	25
Basswood	224	25	199	63	20	43
Beech	4,166	602	3,564	535	111	424
Yellow birch	2,821	265	2,556	248	67	181
Hard maple	6,390	1,249	5,141	308	84	224
Soft maple	8,837	2,735	6,102	631	156	475
Elm	402	47	355	12	--	12
Ash	905	523	382	38	10	28
Balsam poplar	2,876	325	2,551	120	34	86
Bigtooth aspen	2,158	854	1,304	161	15	146
Quaking aspen	10,066	2,315	7,751	996	135	861
Paper birch	5,875	2,599	3,276	493	109	384
Black cherry	252	61	191	15	--	15
Other hardwoods	12	12	--	--	--	--
Total	45,358	11,659	33,699	3,645	741	2,904
All species	89,821	28,713	61,108	5,574	1,246	4,328

(Table 7 continued on next page)

(Table 7 continued)

WESTERN UPPER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	2,197	682	1,515	65	23	42
Red pine	2,011	62	1,949	13	--	13
White pine	5,474	156	5,318	42	17	25
White spruce	6,134	1,076	5,058	44	12	32
Black spruce	1,691	1,005	686	--	--	--
Balsam fir	9,312	5,033	4,279	97	16	81
Hemlock	7,582	467	7,115	310	112	198
Tamarack	454	128	326	32	--	32
Northern white-cedar	9,968	2,004	7,964	1,255	379	876
Total	44,823	10,613	34,210	1,858	559	1,299
HARDWOODS						
White oak	95	--	95	37	--	37
Select red oak	2,093	321	1,772	92	40	52
Basswood	1,268	200	1,068	60	--	60
Beech	25	25	--	11	11	--
Yellow birch	6,143	856	5,287	980	237	743
Hard maple	23,529	5,757	17,772	1,618	415	1,203
Soft maple	9,901	3,740	6,161	907	193	714
Elm	1,677	286	1,391	75	12	63
Ash	2,389	832	1,557	115	9	106
Cottonwood	18	--	18	--	--	--
Balsam poplar	1,435	92	1,343	21	9	12
Bigtooth aspen	2,676	687	1,989	172	11	161
Quaking aspen	15,121	2,637	12,484	1,674	272	1402
Paper birch	6,672	2,279	4,393	379	96	283
Black cherry	837	396	441	39	8	31
Total	73,879	18,108	55,771	6,180	1,313	4,867
All species	118,702	28,721	89,981	8,038	1,872	6,166

NORTHERN LOWER PENINSULA

Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	8,457	3,798	4,659	137	26	111
Red pine	9,797	1,858	7,939	19	10	9
White pine	7,489	598	6,891	57	39	18
White spruce	1,670	438	1,232	12	5	7
Black spruce	448	317	131	7	--	7
Balsam fir	3,442	2,176	1,266	42	14	28
Hemlock	2,699	577	2,122	92	22	70
Tamarack	334	152	182	21	--	21
Northern white-cedar	11,369	5,489	5,880	1,231	229	1,002
Other softwoods	904	627	277	99	--	99
Total	46,609	16,030	30,579	1,717	345	1,372
HARDWOODS						
White oak	5,543	1,286	4,257	309	92	217
Select red oak	17,888	1,815	16,073	758	281	477
Other red oak	2,596	196	2,400	154	42	112
Hickory	37	18	19	--	--	--
Basswood	4,765	606	4,159	121	16	105
Beech	3,185	428	2,757	610	140	470
Yellow birch	999	208	791	80	55	25
Hard maple	13,602	3,205	10,397	565	197	368
Soft maple	16,605	5,701	10,904	677	152	525
Elm	281	69	212	--	--	--
Ash	5,367	2,050	3,317	105	--	105
Cottonwood	384	--	384	--	--	--
Balsam poplar	4,294	347	3,947	228	11	217
Bigtooth aspen	23,189	4,187	19,002	818	78	740
Quaking aspen	20,737	3,628	17,109	1,389	197	1,192
Paper birch	7,198	3,170	4,028	368	38	330
Black cherry	1,469	393	1,076	52	15	37
Other hardwoods	491	70	421	74	--	74
Total	128,630	27,377	101,253	6,308	1,314	4,994
All species	175,239	43,407	131,832	8,025	1,659	6,366

(Table 7 continued on next page)

(Table 7 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	346	59	287	--	--	--
Red pine	811	261	550	13	13	--
White pine	2,426	329	2,097	--	--	--
Hemlock	383	19	364	--	--	--
Tamarack	87	6	81	--	--	--
Northern white-cedar	184	159	25	27	--	27
Other softwoods	609	43	566	--	--	--
Total	4,846	876	3,970	40	13	27
HARDWOODS						
White oak	6,123	564	5,559	67	--	67
Select red oak	8,504	623	7,881	175	22	153
Other red oak	1,503	--	1,503	38	22	16
Hickory	1,767	247	1,520	--	--	--
Basswood	2,530	722	1,808	112	8	104
Beech	1,083	28	1,055	156	45	111
Yellow birch	191	--	191	17	11	6
Hard maple	3,265	201	3,064	126	--	126
Soft maple	9,854	1,745	8,109	356	51	305
Elm	969	677	292	--	--	--
Ash	3,989	650	3,339	122	22	100
Cottonwood	1,988	19	1,969	15	--	15
Balsam poplar	341	133	208	--	--	--
Bigtooth aspen	2,489	403	2,086	42	--	42
Quaking aspen	1,715	758	957	12	--	12
Paper birch	233	55	178	--	--	--
Black cherry	1,231	390	841	238	125	113
Other hardwoods	1,488	250	1,238	230	4	226
Total	49,263	7,465	41,798	1,706	310	1,396
All species	54,109	8,341	45,768	1,746	323	1,423

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 8.--Average annual yields of growing stock from harvest by species group, forest type, and Forest Survey Unit, Michigan, 1981-1990[1]/

(In thousand cubic feet)

ALL UNITS

		Forest type													
Species group	All types	Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	15,300	13,074	968	--	7	219	20	--	--	585	--	14	281	46	86
Red pine	16,116	1,300	11,398	306	67	140	189	--	11	273	--	281	1,503	202	446
White pine	20,208	377	2,544	4,059	259	595	1,560	--	1,159	1,650	1,177	3,136	3,069	373	250
White spruce	10,721	15	222	246	930	244	2,307	--	1,163	50	425	1,389	3,435	295	--
Black spruce	5,503	113	163	39	104	2,797	407	109	844	--	125	212	481	109	--
Balsam fir	19,119	17	89	77	373	681	5,826	45	1,110	20	782	2,112	7,324	663	--
Hemlock	14,573	--	143	7	9	92	378	--	570	--	629	12,071	570	104	--
Tamarack	1,458	--	--	--	--	82	69	775	174	--	50	118	165	25	--
Northern white-cedar	36,230	--	55	66	527	2,237	2,419	142	16,276	44	2,083	4,104	7,205	1,060	12
Other softwoods	1,513	--	104	--	--	--	--	--	--	22	--	--	--	--	1,387
Total	140,741	14,896	15,686	4,800	2,276	7,087	13,175	1,071	21,307	2,644	5,271	23,437	24,033	2,877	2,181
HARDWOODS															
White oak	11,761	160	141	--	--	--	--	--	--	9,227	338	1,128	749	18	--
Select red oak	28,859	1,307	971	123	--	--	--	--	--	16,516	139	3,745	5,830	226	2
Other red oak	4,099	452	111	--	--	--	--	--	--	3,215	143	66	74	--	38
Hickory	1,804	--	--	--	--	--	--	--	--	925	121	758	--	--	--
Basswood	8,787	--	44	--	--	--	--	--	--	155	991	6,078	1,384	135	--
Beech	8,459	--	--	24	--	--	--	--	--	91	23	8,207	114	--	--
Yellow birch	10,154	--	--	45	--	114	524	--	337	18	699	7,967	323	127	--
Hard maple	46,786	--	39	107	4	25	155	--	334	284	375	41,416	3,535	512	--
Soft maple	45,197	269	311	298	116	248	1,656	--	777	2,159	10,533	16,591	10,960	1,279	--
Elm	3,329	--	--	--	12	--	45	--	1	75	631	1,917	625	9	14
Ash	12,650	--	--	--	--	116	246	--	323	682	4,577	5,040	1,543	123	--
Cottonwood	2,390	--	--	--	--	--	--	--	--	180	941	501	768	--	--
Balsam poplar	8,946	--	9	--	20	27	328	--	249	--	383	315	7,514	101	--
Bigtooth aspen	30,512	46	430	47	--	--	3	--	132	1,245	120	1,388	26,592	470	39
Quaking aspen	47,639	242	337	252	117	328	1,373	9	416	215	705	2,247	40,513	814	71
Paper birch	19,978	75	217	156	116	301	1,040	--	1,051	295	386	1,910	9,348	5,083	--
Black cherry	3,789	30	171	--	--	--	138	--	15	748	292	1,279	1,082	10	24
Other hardwoods	1,991	--	23	--	--	--	--	--	22	396	487	920	123	20	--
Total	297,130	2,581	2,804	1,052	385	1,159	5,508	9	3,657	36,426	21,884	101,473	111,077	8,927	188
All species	437,871	17,477	18,490	5,852	2,661	8,246	18,683	1,080	24,964	39,070	27,155	124,910	135,110	11,804	2,369

(Table 8 continued on next page)

(Table 8 continued)

WESTERN UPPER PENINSULA

Species group	All types	Forest type												
		Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	2,197	1,994	11	--	--	60	20	--	--	--	--	--	66	46	--
Red pine	2,011	47	1,172	181	15	85	189	--	--	6	--	31	285	--	--
White pine	5,474	29	425	764	183	198	1,031	--	126	--	23	1,430	1,048	217	--
White spruce	6,134	15	71	196	457	201	1,912	--	166	13	262	1,248	1,409	179	--
Black spruce	1,691	36	28	--	95	583	353	39	138	--	24	132	174	89	--
Balsam fir	9,312	--	51	10	159	524	3,503	21	302	20	253	1,496	2,576	397	--
Hemlock	7,582	--	--	--	--	48	155	--	10	--	233	7,041	95	--	--
Tamarack	454	--	--	--	--	9	59	210	2	--	50	--	99	25	--
Northern white-cedar	9,968	--	--	--	172	1,757	1,371	10	3,338	--	649	2,032	274	365	--
Total	44,823	2,121	1,758	1,151	1,081	3,465	8,593	280	4,082	44	1,494	13,410	6,026	1,318	--
HARDWOODS															
White oak	95	--	--	--	--	--	--	--	--	--	--	--	95	--	--
Select red oak	2,093	61	76	--	--	--	--	--	--	268	--	721	799	168	--
Basswood	1,268	--	--	--	--	--	--	--	--	--	53	997	218	--	--
Beech	25	--	--	--	--	--	--	--	--	--	--	25	--	--	--
Yellow birch	6,143	--	--	3	--	114	388	--	74	18	357	5,044	125	20	--
Hard maple	23,529	--	--	107	4	25	145	--	151	83	109	20,794	1,810	301	--
Soft maple	9,901	10	36	106	19	126	949	--	146	8	704	5,346	1,955	496	--
Elm	1,677	--	--	--	12	--	45	--	--	--	135	1,175	310	--	--
Ash	2,389	--	--	--	--	116	129	--	34	--	1,424	473	202	11	--
Cottonwood	18	--	--	--	--	--	--	--	--	--	--	--	18	--	--
Balsam poplar	1,435	--	9	--	--	--	113	--	--	--	--	86	1,207	20	--
Bigtooth aspen	2,676	14	118	--	--	--	3	--	--	--	--	176	2,137	228	--
Quaking aspen	15,121	12	36	195	51	169	688	--	10	7	13	1,266	12,235	439	--
Paper birch	6,672	26	60	8	86	59	481	--	215	--	71	1,016	2,277	2,373	--
Black cherry	837	--	--	--	--	--	138	--	--	--	--	344	345	10	--
Total	73,879	123	335	419	172	609	3,079	--	630	384	2,866	37,463	23,733	4,066	--
All species	118,702	2,244	2,093	1,570	1,253	4,074	11,672	280	4,712	428	4,360	50,873	29,759	5,384	--

(Table 8 continued on next page)

(Table 8 continued)

NORTHERN LOWER PENINSULA

Species group	All types	Forest type: Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	8,457	6,939	735	--	--	--	--	--	--	585	--	14	136	--	48
Red pine	9,797	669	7,123	17	--	--	--	--	--	267	--	250	1,009	117	345
White pine	7,489	169	1,372	1,420	--	--	159	--	263	851	862	838	1,411	120	24
White spruce	1,670	--	127	--	127	--	74	--	614	--	27	--	680	21	--
Black spruce	448	--	60	16	--	150	--	34	41	--	29	--	118	--	--
Balsam fir	3,442	17	38	--	105	--	623	--	228	--	277	15	2,086	53	--
Hemlock	2,699	--	143	--	--	--	--	--	284	--	96	1,829	297	50	--
Tamarack	334	--	--	--	--	--	--	129	108	--	--	41	56	--	--
Northern white-cedar	11,369	--	55	63	174	259	77	--	4,678	44	1,055	846	4,053	53	12
Other softwoods	904	--	104	--	--	--	--	--	--	--	--	--	--	--	800
Total	46,609	7,794	9,757	1,516	406	409	933	163	6,216	1,747	2,346	3,833	9,846	414	1,229
HARDWOODS															
White oak	5,543	160	141	--	--	--	--	--	--	4,408	30	210	576	18	--
Select red oak	17,888	1,238	895	93	--	--	--	--	--	10,024	11	1,223	4,346	58	--
Other red oak	2,596	452	111	--	--	--	--	--	--	1,920	--	39	74	--	--
Hickory	37	--	--	--	--	--	--	--	--	--	--	37	--	--	--
Basswood	4,765	--	44	--	--	--	--	--	--	40	253	3,264	1,101	63	--
Beech	3,185	--	--	--	--	--	--	--	--	91	--	2,992	102	--	--
Yellow birch	999	--	--	42	--	--	--	--	55	--	122	610	119	51	--
Hard maple	13,602	--	39	--	--	--	--	--	--	127	46	12,313	947	130	--
Soft maple	16,605	172	275	68	--	--	187	--	184	1,371	2,882	3,174	7,720	572	--
Elm	281	--	--	--	--	--	--	--	--	--	--	232	35	--	14
Ash	5,367	--	--	--	--	--	45	--	139	159	1,458	2,552	967	47	--
Cottonwood	384	--	--	--	--	--	--	--	--	--	266	--	118	--	--
Balsam poplar	4,294	--	--	--	1	--	35	--	177	--	352	129	3,600	--	--
Bigtooth aspen	23,189	32	243	38	--	--	--	--	132	959	120	1,013	20,480	133	39
Quaking aspen	20,737	210	249	17	--	--	91	9	155	196	282	860	18,345	255	68
Paper birch	7,198	36	55	22	--	--	71	--	269	288	111	630	4,613	1,103	--
Black cherry	1,469	18	69	--	--	--	--	--	15	102	35	594	614	--	22
Other hardwoods	491	--	23	--	--	--	--	--	14	114	233	--	87	20	--
Total	128,630	2,318	2,144	280	1	--	429	9	1,140	19,799	6,201	29,872	63,844	2,450	143
All species	175,239	10,112	11,901	1,796	407	409	1,362	172	7,356	21,546	8,547	33,705	73,690	2,864	1,372

(Table 8 continued on next page)

(Table 8 continued)

EASTERN UPPER PENINSULA

Species group	All types	Forest type												
		Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	4,300	3,833	222	--	7	159	--	--	--	--	--	--	79	--	--
Red pine	3,497	584	2,393	108	52	55	--	--	11	--	--	--	209	85	--
White pine	4,819	179	747	1,040	76	397	370	--	770	23	156	651	374	36	--
White spruce	2,917	--	24	50	346	43	321	--	383	32	136	141	1,346	95	--
Black spruce	3,364	77	75	23	9	2,064	54	36	665	--	72	80	189	20	--
Balsam fir	6,365	--	--	67	109	157	1,700	24	580	--	252	601	2,662	213	--
Hemlock	3,909	--	--	7	9	44	223	--	276	--	300	2,818	178	54	--
Tamarack	583	--	--	--	--	73	10	436	54	--	--	--	10	--	--
Northern white-cedar	14,709	--	--	3	181	221	971	132	8,211	--	379	1,091	2,878	642	--
Total	44,463	4,673	3,461	1,298	789	3,213	3,649	628	10,950	55	1,295	5,382	7,925	1,145	--
HARDWOODS															
Select red oak	374	8	--	--	--	--	--	--	--	231	4	29	102	--	--
Basswood	224	--	--	--	--	--	--	--	--	36	--	123	65	--	--
Beech	4,166	--	--	24	--	--	--	--	--	--	23	4,107	12	--	--
Yellow birch	2,821	--	--	--	--	--	136	--	208	--	220	2,122	79	56	--
Hard maple	6,390	--	--	--	--	--	10	--	183	7	37	5,294	778	81	--
Soft maple	8,837	24	--	124	97	122	520	--	447	48	1,930	4,430	908	187	--
Elm	402	--	--	--	--	--	--	--	--	--	88	157	148	9	--
Ash	905	--	--	--	--	--	72	--	148	--	239	169	212	65	--
Balsam poplar	2,876	--	--	--	19	27	180	--	72	--	6	73	2,418	81	--
Bigtooth aspen	2,158	--	69	9	--	--	--	--	--	--	--	23	1,948	109	--
Quaking aspen	10,066	20	52	40	66	159	594	--	245	12	23	78	8,665	112	--
Paper birch	5,875	13	102	126	30	242	488	--	554	7	55	264	2,428	1,566	--
Black cherry	252	12	59	--	--	--	--	--	--	--	25	134	22	--	--
Other hardwoods	12	--	--	--	--	--	--	--	--	--	--	--	12	--	--
Total	45,358	77	282	323	212	550	2,000	--	1,857	341	2,650	17,003	17,797	2,266	--
All species	89,821	4,750	3,743	1,621	1,001	3,763	5,649	628	12,807	396	3,945	22,385	25,722	3,411	--

(Table 8 continued on next page)

(Table 8 continued)

SOUTHERN LOWER PENINSULA

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	346	308	--	--	--	--	--	--	--	--	--	--	--	--	38
Red pine	811	--	710	--	--	--	--	--	--	--	--	--	--	--	101
White pine	2,426	--	--	835	--	--	--	--	--	776	136	217	236	--	226
Hemlock	383	--	--	--	--	--	--	--	--	--	--	383	--	--	--
Tamarack	87	--	--	--	--	--	--	--	10	--	--	77	--	--	--
Northern white-cedar	184	--	--	--	--	--	--	--	49	--	--	135	--	--	--
Other softwoods	609	--	--	--	--	--	--	--	--	22	--	--	--	--	587
Total	4,846	308	710	835	--	--	--	--	59	798	136	812	236	--	952
HARDWOODS															
White oak	6,123	--	--	--	--	--	--	--	--	4,819	308	918	78	--	--
Select red oak	8,504	--	--	30	--	--	--	--	--	5,993	124	1,772	583	--	2
Other red oak	1,503	--	--	--	--	--	--	--	--	1,295	143	27	--	--	38
Hickory	1,767	--	--	--	--	--	--	--	--	925	121	721	--	--	--
Basswood	2,530	--	--	--	--	--	--	--	--	79	685	1,694	--	72	--
Beech	1,083	--	--	--	--	--	--	--	--	--	--	1,083	--	--	--
Yellow-birch	191	--	--	--	--	--	--	--	--	--	--	191	--	--	--
Hard maple	3,265	--	--	--	--	--	--	--	--	67	183	3,015	--	--	--
Soft maple	9,854	63	--	--	--	--	--	--	--	732	5,017	3,641	377	24	--
Elm	969	--	--	--	--	--	--	--	1	75	408	353	132	--	--
Ash	3,989	--	--	--	--	--	--	--	2	523	1,456	1,846	162	--	--
Cottonwood	1,988	--	--	--	--	--	--	--	--	180	675	501	632	--	--
Balsam poplar	341	--	--	--	--	--	--	--	--	--	25	27	289	--	--
Bigtooth aspen	2,489	--	--	--	--	--	--	--	--	286	--	176	2,027	--	--
Quaking aspen	1,715	--	--	--	--	--	--	--	6	--	387	43	1,268	8	3
Paper birch	233	--	--	--	--	--	--	--	13	--	149	--	30	41	--
Black cherry	1,231	--	43	--	--	--	--	--	--	646	232	207	101	--	2
Other hardwoods	1,488	--	--	--	--	--	--	--	8	282	254	920	24	--	--
Total	49,263	63	43	30	--	--	--	--	30	15,902	10,167	17,135	5,703	145	45
All species	54,109	371	753	865	--	--	--	--	89	16,700	10,303	17,947	5,939	145	997

[1] Tables may not add to totals due to rounding.

Table 9.--Average annual yields of growing stock from harvest by forest type, stand age class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

		Stand-age class (years)										
Forest type	All ages	1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
ALL UNITS												
Jack pine	17,477	--	--	--	6,016	4,749	4,463	1,446	505	193	105	--
Red pine	18,490	--	--	4,523	1,034	2,927	2,468	1,715	1,863	3,719	241	--
White pine	5,852	--	--	--	--	--	865	--	522	573	2,756	1,136
White spruce	2,661	--	--	--	--	--	--	683	--	1,572	--	406
Black spruce	8,246	--	--	--	556	1,221	1,504	375	903	1,877	1,119	691
Balsam fir	18,683	--	--	--	1,590	1,410	3,491	3,183	2,740	3,915	1,707	647
Tamarack	1,080	--	--	--	--	94	177	167	235	215	--	192
Northern white-cedar	24,964	--	--	--	--	--	46	--	--	4,191	10,671	10,056
Oak-hickory	39,070	--	--	--	--	--	--	--	7,704	23,261	7,213	892
Elm-ash-maple	27,155	--	--	--	--	--	--	--	3,623	14,499	6,260	2,773
Maple-birch	124,910	--	--	--	--	--	--	--	16,589	40,267	51,744	16,310
Aspen	135,110	--	--	470	28,930	41,253	28,512	14,876	10,123	9,539	1,407	--
Paper birch	11,804	--	145	--	--	2,459	3,924	1,478	2,022	615	877	284
Exotic	2,369	--	931	260	1,178	--	--	--	--	--	--	--
All types	437,871	--	1,076	5,253	39,304	54,113	45,450	23,923	46,829	104,436	84,100	33,387
EASTERN UPPER PENINSULA												
Jack pine	4,750	--	--	--	2,141	1,544	609	456	--	--	--	--
Red pine	3,743	--	--	245	414	669	1,066	117	308	924	--	--
White pine	1,621	--	--	--	--	--	--	--	--	60	814	747
White spruce	1,001	--	--	--	--	--	--	682	--	319	--	--
Black spruce	3,763	--	--	--	556	1,221	840	375	486	152	--	133
Balsam fir	5,649	--	--	--	1,590	1,410	773	222	412	944	298	--
Tamarack	628	--	--	--	--	--	177	167	178	106	--	--
Northern white-cedar	12,807	--	--	--	--	--	--	--	--	2,272	5,796	4,739
Oak-hickory	396	--	--	--	--	--	--	--	154	--	242	--
Elm-ash-maple	3,945	--	--	--	--	--	--	--	--	2,499	1,085	361
Maple-birch	22,385	--	--	--	--	--	--	--	--	5,599	12,023	4,763
Aspen	25,722	--	--	--	8,722	7,949	2,207	1,863	3,595	1,386	--	--
Paper birch	3,411	--	--	--	--	1,301	1,021	--	474	615	--	--
All types	89,821	--	--	245	13,423	14,094	6,693	3,882	5,607	14,876	20,258	10,743

(Table 9 continued on next page)

(Table 9 continued)

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
WESTERN UPPER PENINSULA												
Jack pine	2,244	--	--	--	635	656	510	268	175	--	--	--
Red pine	2,093	--	--	--	--	--	--	--	144	1,708	241	--
White pine	1,570	--	--	--	--	--	--	--	--	195	986	389
White spruce	1,253	--	--	--	--	--	--	--	--	1,253	--	--
Black spruce	4,074	--	--	--	--	--	255	--	417	1,725	1,119	558
Balsam fir	11,672	--	--	--	--	--	2,718	2,940	2,328	2,688	351	647
Tamarack	280	--	--	--	--	31	--	--	57	--	--	192
Northern white-cedar	4,712	--	--	--	--	--	--	--	--	--	2,166	2,546
Oak-hickory	428	--	--	--	--	--	--	--	--	87	341	--
Elm-ash-maple	4,360	--	--	--	--	--	--	--	--	--	1,948	2,412
Maple-birch	50,873	--	--	--	--	--	--	--	--	7,317	32,009	11,547
Aspen	29,759	--	--	--	6,052	7,654	9,559	4,097	720	1,677	--	--
Paper birch	5,384	--	--	--	--	--	1,615	1,472	1,136	--	877	284
All types	118,702	--	--	--	6,687	8,341	14,657	8,777	4,977	16,650	40,038	18,575
NORTHERN LOWER PENINSULA												
Jack pine	10,112	--	--	--	3,240	2,178	3,344	722	330	193	105	--
Red pine	11,901	--	--	3,525	620	2,258	1,402	1,598	1,411	1,087	--	--
White pine	1,796	--	--	--	--	--	--	--	522	318	956	--
White spruce	407	--	--	--	--	--	--	1	--	--	--	406
Black spruce	409	--	--	--	--	--	409	--	--	--	--	--
Balsam fir	1,362	--	--	--	--	--	--	21	--	283	1,058	--
Tamarack	172	--	--	--	--	63	--	--	--	109	--	--
Northern white-cedar	7,356	--	--	--	--	--	--	--	--	1,876	2,709	2,771
Oak-hickory	21,546	--	--	--	--	--	--	--	7,550	11,016	2,739	241
Elm-ash-maple	8,547	--	--	--	--	--	--	--	1,179	4,997	2,371	--
Maple-birch	33,705	--	--	--	--	--	--	--	14,045	15,724	3,936	--
Aspen	73,690	--	--	--	12,565	22,247	16,271	8,916	5,808	6,476	1,407	--
Paper birch	2,864	--	--	--	--	1,158	1,288	6	412	--	--	--
Exotic	1,372	--	909	260	203	--	--	--	--	--	--	--
All types	175,239	--	909	3,785	16,628	27,904	22,714	11,264	31,257	42,079	15,281	3,418
SOUTHERN LOWER PENINSULA												
Jack pine	371	--	--	--	--	371	--	--	--	--	--	--
Red pine	753	--	--	753	--	--	--	--	--	--	--	--
White pine	865	--	--	--	--	--	865	--	--	--	--	--
Northern white-cedar	89	--	--	--	--	--	46	--	--	43	--	--
Oak-hickory	16,700	--	--	--	--	--	--	--	--	12,158	3,891	651
Elm-ash-maple	10,303	--	--	--	--	--	--	--	2,444	7,003	856	--
Maple-birch	17,947	--	--	--	--	--	--	--	2,544	11,627	3,776	--
Aspen	5,939	--	--	470	1,591	3,403	475	--	--	--	--	--
Paper birch	145	--	145	--	--	--	--	--	--	--	--	--
Exotic	997	--	22	--	975	--	--	--	--	--	--	--
All types	54,109	--	167	1,223	2,566	3,774	1,386	--	4,988	30,831	8,523	651

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[1] Tables may not add to totals due to rounding.

Table 10.--Commercial forest area qualifying for thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand acres)

Forest type	All ages	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS									
Red pine	139.0	--	76.8	49.4	12.9	--	--	--	--
White pine	3.3	--	--	--	3.3	--	--	--	--
White spruce	9.1	--	--	--	9.1	--	--	--	--
Oak-hickory	191.5	--	11.5	73.6	106.4	--	--	--	--
Maple-birch	1,975.3	--	65.0	181.2	604.2	575.0	327.1	222.8	--
All types	2,318.4	--	153.3	304.2	735.9	575.0	327.1	222.8	--
EASTERN UPPER PENINSULA									
Red pine	14.3	--	9.6	3.0	1.7	--	--	--	--
White spruce	7.4	--	--	--	7.4	--	--	--	--
Oak-hickory	1.9	--	--	0.4	1.5	--	--	--	--
Maple-birch	419.0	--	19.7	39.6	132.7	101.8	84.2	41.0	--
All types	442.6	--	29.4	42.9	143.3	101.8	84.2	41.0	--
WESTERN UPPER PENINSULA									
Red pine	13.7	--	7.7	6.0	--	--	--	--	--
White spruce	1.7	--	--	--	1.7	--	--	--	--
Oak-hickory	6.6	--	1.6	1.7	3.3	--	--	--	--
Maple-birch	827.3	--	18.1	67.5	268.4	265.5	118.9	89.0	--
All types	849.4	--	27.4	75.2	273.4	265.5	118.9	89.0	--
NORTHERN LOWER PENINSULA									
Red pine	101.8	--	56.9	37.1	7.9	--	--	--	--
Oak-hickory	103.9	--	9.9	38.0	56.0	--	--	--	--
Maple-birch	589.6	--	9.5	45.7	179.1	188.3	98.5	68.5	--
All types	795.4	--	76.3	120.8	243.0	188.3	98.5	68.5	--
SOUTHERN LOWER PENINSULA									
Red pine	9.2	--	2.6	3.3	3.3	--	--	--	--
White pine	3.3	--	--	--	3.3	--	--	--	--
Oak-hickory	79.1	--	--	33.5	45.6	--	--	--	--
Maple-birch	139.3	--	17.7	28.4	24.0	19.5	25.4	24.4	--
All types	231.0	--	20.3	65.2	76.2	19.5	25.4	24.4	--

[1] Tables may not add to totals due to rounding.

Table 11.--Average annual yields from thinning by species group, tree class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
ALL UNITS						
SOFTWOODS						
Jack pine	1,593	1,258	335	131	35	96
Red pine	11,000	9,912	1,088	186	--	186
White pine	965	412	553	51	13	38
White spruce	573	446	127	--	--	--
Black spruce	284	235	49	--	--	--
Balsam fir	3,892	3,298	594	35	5	30
Hemlock	2,026	894	1,132	150	--	150
Tamarack	10	10	--	--	--	--
Northern white-cedar	1,167	825	342	230	14	216
Other softwoods	273	251	22	--	--	--
Total	21,783	17,541	4,242	783	67	716
HARDWOODS						
White oak	1,505	981	524	214	15	199
Select red oak	2,582	1,725	857	272	65	207
Other red oak	846	455	391	52	52	--
Hickory	368	156	212	32	--	32
Basswood	7,351	4,270	3,081	422	110	312
Beech	792	474	318	168	50	118
Yellow birch	922	737	185	115	19	96
Hard maple	35,817	22,572	13,245	2,641	353	2,288
Soft maple	29,449	18,813	10,636	2,052	223	1,829
Elm	4,154	2,245	1,909	235	39	196
Ash	5,848	3,291	2,557	178	39	139
Cottonwood	176	27	149	--	--	--
Balsam poplar	142	44	98	1	--	1
Bigtooth aspen	3,107	1,769	1,338	142	--	142
Quaking aspen	4,079	2,120	1,959	252	7	245
Paper birch	3,067	1,722	1,345	186	16	170
Black cherry	4,299	2,381	1,918	390	33	357
Other hardwoods	657	239	418	29	29	--
Total	105,161	64,021	41,140	7,381	1,050	6,331
All species	126,944	81,562	45,382	8,164	1,117	7,047
EASTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	119	57	62	17	10	7
Red pine	887	771	116	--	--	--
White pine	212	94	118	9	9	--
White spruce	161	146	15	--	--	--
Black spruce	76	41	35	--	--	--
Balsam fir	906	748	158	9	--	9
Hemlock	363	132	231	57	--	57
Northern white-cedar	240	178	62	17	--	17
Total	2,964	2,167	797	109	19	90
HARDWOODS						
Select red oak	105	74	31	--	--	--
Basswood	592	269	323	41	--	41
Beech	144	133	11	43	18	25
Yellow birch	64	29	35	7	--	7
Hard maple	7,772	3,983	3,789	491	210	281
Soft maple	8,731	5,035	3,696	739	46	693
Elm	668	278	390	48	--	48
Ash	323	228	95	13	--	13
Balsam poplar	58	23	35	1	--	1
Bigtooth aspen	138	51	87	32	--	32
Quaking aspen	524	238	286	59	7	52
Paper birch	872	442	430	89	7	82
Black cherry	930	491	439	97	--	97
Total	20,921	11,274	9,647	1,660	288	1,372
All species	23,885	13,441	10,444	1,769	307	1,462

(Table 11 continued on next page)

(Table 11 continued)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2/]
WESTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	154	127	27	8	--	8
Red pine	683	683	0	29	--	29
White pine	287	77	210	3	--	3
White spruce	412	300	112	--	--	--
Black spruce	208	194	14	--	--	--
Balsam fir	2,825	2,411	414	26	5	21
Hemlock	1,113	353	760	85	--	85
Norther white-cedar	467	296	171	108	--	108
Other softwoods	22	--	22	--	--	--
Total	6,171	4,441	1,730	259	5	254
HARDWOODS						
Select red oak	318	232	86	31	--	31
Basswood	3,146	1,795	1,351	133	73	60
Yellow birch	745	635	110	100	19	81
Hard maple	14,787	10,209	4,578	1,563	74	1,489
Soft maple	11,920	8,590	3,330	846	85	761
Elm	2,527	1,254	1,273	84	39	45
Ash	1,674	1,272	402	71	8	63
Balsam poplar	70	7	63	--	--	--
Bigtooth aspen	422	247	175	37	--	37
Quaking aspen	2,258	1,067	1,191	108	--	108
Paper birch	854	472	382	43	9	34
Black cherry	1,112	751	361	88	--	88
Total	39,833	26,531	13,302	3,104	307	2,797
All species	46,004	30,972	15,032	3,363	312	3,051
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	1,300	1,074	226	106	25	81
Red pine	8,743	7,982	761	130	--	130
White pine	244	130	114	39	4	35
Balsam fir	139	139	--	--	--	--
Hemlock	534	393	141	8	--	8
Tamarack	10	10	--	--	--	--
Northern white-cedar	460	351	109	105	14	91
Other softwoods	166	166	--	--	--	--
Total	11,596	10,245	1,351	388	43	345
HARDWOODS						
White oak	919	564	355	80	15	65
Select red oak	1,522	982	540	222	65	157
Other red oak	642	281	361	--	--	--
Hickory	41	17	24	--	--	--
Basswood	3,581	2,174	1,407	248	37	211
Beech	648	341	307	125	32	93
Yellow birch	113	73	40	8	--	8
Hard maple	12,498	8,295	4,203	528	49	479
Soft maple	7,505	4,676	2,829	222	60	162
Elm	520	361	159	16	--	16
Ash	2,938	1,189	1,749	69	31	38
Balsam poplar	14	14	--	--	--	--
Bigtooth aspen	2,195	1,190	1,005	73	--	73
Quaking aspen	1,017	637	380	85	--	85
Paper birch	1,305	808	497	54	--	54
Black cherry	1,370	666	704	152	33	119
Total	36,828	22,268	14,560	1,882	322	1,560
All species	48,424	32,513	15,911	2,270	365	1,905

(Table 11 continued on next page)

(Table 11 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	20	--	20	--	--	--
Red pine	687	476	211	27	--	27
White pine	222	111	111	--	--	--
Balsam fir	22	--	22	--	--	--
Hemlock	16	16	--	--	--	--
Other softwoods	85	85	--	--	--	--
Total	1,052	688	364	27	--	27
HARDWOODS						
White oak	586	417	169	134	--	134
Select red oak	637	437	200	19	--	19
Other red oak	204	174	30	52	52	--
Hickory	327	139	188	32	--	32
Basswood	32	32	--	--	--	--
Hard maple	760	85	675	59	20	39
Soft maple	1,293	512	781	245	32	213
Elm	439	352	87	87	--	87
Ash	913	602	311	25	--	25
Cottonwood	176	27	149	--	--	--
Bigtooth aspen	352	281	71	--	--	--
Quaking aspen	280	178	102	--	--	--
Paper birch	36	--	36	--	--	--
Black cherry	887	473	414	53	--	53
Other hardwoods	657	239	418	29	29	--
Total	7,579	3,948	3,631	735	133	602
All species	8,631	4,636	3,995	762	133	629

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 12.--Average annual yields of growing stock from thinning by species group, forest type, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

ALL UNITS

		Forest type[2]					
Species group	All types	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Jack pine	1,593	1,415	--	13	--	165	--
Red pine	11,000	10,021	73	28	--	471	407
White pine	965	159	66	107	--	74	559
White spruce	573	--	--	--	--	--	573
Black spruce	284	--	--	14	--	--	270
Balsam fir	3,892	125	--	43	--	--	3,724
Hemlock	2,026	--	--	8	--	--	2,018
Tamarack	10	--	--	--	--	--	10
Northern white-cedar	1,167	--	--	35	--	--	1,132
Other softwoods	273	63	--	--	--	--	210
Total	21,783	11,783	139	248	--	710	8,903
HARDWOODS							
White oak	1,505	522	--	--	--	725	258
Select red oak	2,582	156	--	--	--	1,095	1,331
Other red oak	846	380	--	--	--	445	21
Hickory	368	--	--	--	--	46	322
Basswood	7,351	--	--	--	--	--	7,351
Beech	792	54	--	11	--	--	727
Yellow birch	922	--	--	--	--	--	922
Hard maple	35,817	19	--	--	--	--	35,798
Soft maple	29,449	427	--	12	--	839	28,171
Elm	4,154	--	--	13	--	103	4,038
Ash	5,848	7	--	--	--	96	5,745
Cottonwood	176	--	--	--	--	87	89
Balsam poplar	142	--	--	24	--	--	118
Bigtooth aspen	3,107	131	--	--	--	1,291	1,685
Quaking aspen	4,079	171	--	180	--	297	3,431
Paper birch	3,067	25	--	125	--	259	2,658
Black cherry	4,299	97	87	--	--	305	3,810
Other hardwoods	657	--	--	--	--	329	328
Total	105,161	1,989	87	365	--	5,917	96,803
All species	126,944	13,772	226	613	--	6,627	105,706
EASTERN UPPER PENINSULA							
SOFTWOODS							
Jack pine	119	116	--	--	--	3	--
Red pine	887	856	--	28	--	3	--
White pine	212	--	--	107	--	--	105
White spruce	161	--	--	--	--	--	161
Black spruce	76	--	--	--	--	--	76
Balsam fir	906	58	--	30	--	--	818
Hemlock	363	--	--	8	--	--	355
Northern white-cedar	240	--	--	35	--	--	205
Total	2,964	1,030	--	208	--	6	1,720
HARDWOODS							
Select red oak	105	--	--	--	--	28	77
Basswood	592	--	--	--	--	--	592
Beech	144	--	--	11	--	--	133
Yellow birch	64	--	--	--	--	--	64
Hard maple	7,772	--	--	--	--	--	7,772
Soft maple	8,731	28	--	12	--	--	8,691
Elm	668	--	--	13	--	--	655
Ash	323	--	--	--	--	--	323
Balsam poplar	58	--	--	24	--	--	34
Bigtooth aspen	138	--	--	--	--	--	138
Quaking aspen	524	--	--	122	--	--	402
Paper birch	872	--	--	82	--	--	790
Black cherry	930	28	--	--	--	--	902
Total	20,921	56	--	264	--	28	20,573
All species	23,885	1,086	--	472	--	34	22,293

(Table 12 continued on next page)

(Table 12 continued)

Species group	All types	Forest type[2]					
		Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
WESTERN UPPER PENINSULA							
SOFTWOODS							
Jack pine	154	141	--	13	--	--	--
Red pine	683	651	--	--	--	28	4
White pine	287	--	--	--	--	11	276
White spruce	412	--	--	--	--	--	412
Black spruce	208	--	--	14	--	--	194
Balsam fir	2,825	45	--	13	--	--	2,767
Hemlock	1,113	--	--	--	--	--	1,113
Northern white-cedar	467	--	--	--	--	--	467
Other softwoods	22	22	--	--	--	--	--
Total	6,171	859	--	40	--	39	5,233
HARDWOODS							
Select red oak	318	22	--	--	--	20	276
Basswood	3,146	--	--	--	--	--	3,146
Yellow birch	745	--	--	--	--	--	745
Hard maple	14,787	19	--	--	--	--	14,768
Soft maple	11,920	--	--	--	--	104	11,816
Elm	2,527	--	--	--	--	--	2,527
Ash	1,674	--	--	--	--	--	1,674
Balsam poplar	70	--	--	--	--	--	70
Bigtooth aspen	422	47	--	--	--	151	224
Quaking aspen	2,258	171	--	58	--	14	2,015
Paper birch	854	25	--	43	--	112	674
Black cherry	1,112	--	--	--	--	--	1,112
Total	39,833	284	--	101	--	401	39,047
All species	46,004	1,143	--	141	--	440	44,280
NORTHERN LOWER PENINSULA							
SOFTWOODS							
Jack pine	1,300	1,138	--	--	--	162	--
Red pine	8,743	7,900	--	--	--	440	403
White pine	244	66	--	--	--	--	178
Balsam fir	139	--	--	--	--	--	139
Hemlock	534	--	--	--	--	--	534
Tamarack	10	--	--	--	--	--	10
Northern white-cedar	460	--	--	--	--	--	460
Other softwoods	166	41	--	--	--	--	125
Total	11,596	9,145	--	--	--	602	1,849
HARDWOODS							
White oak	919	522	--	--	--	352	45
Select red oak	1,522	90	--	--	--	758	674
Other red oak	642	380	--	--	--	241	21
Hickory	41	--	--	--	--	--	41
Basswood	3,581	--	--	--	--	--	3,581
Beech	648	54	--	--	--	--	594
Yellow birch	113	--	--	--	--	--	113
Hard maple	12,498	--	--	--	--	--	12,498
Soft maple	7,505	399	--	--	--	601	6,505
Elm	520	--	--	--	--	--	520
Ash	2,938	7	--	--	--	28	2,903
Balsam poplar	14	--	--	--	--	--	14
Bigtooth aspen	2,195	67	--	--	--	842	1,286
Quaking aspen	1,017	--	--	--	--	125	892
Paper birch	1,305	--	--	--	--	111	1,194
Black cherry	1,370	69	--	--	--	42	1,259
Total	36,828	1,588	--	--	--	3,100	32,140
All species	48,424	10,733	--	--	--	3,702	33,989

(Table 12 continued on next page)

(Table 12 continued)

SOUTHERN LOWER PENINSULA

		Forest type[2]					
Species group	All types	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Jack pine	20	20	--	--	--	--	--
Red pine	687	614	73	--	--	--	--
White pine	222	93	66	--	--	63	--
Balsam fir	22	22	--	--	--	--	--
Hemlock	16	--	--	--	--	--	16
Other softwoods	85	--	--	--	--	--	85
Total	1,052	749	139	--	--	63	101
HARDWOODS							
White oak	586	--	--	--	--	373	213
Select red oak	637	44	--	--	--	289	304
Other red oak	204	--	--	--	--	204	--
Hickory	327	--	--	--	--	46	281
Basswood	32	--	--	--	--	--	32
Hard maple	760	--	--	--	--	--	760
Soft maple	1,293	--	--	--	--	134	1,159
Elm	439	--	--	--	--	103	336
Ash	913	--	--	--	--	68	845
Cottonwood	176	--	--	--	--	87	89
Bigtooth aspen	352	17	--	--	--	298	37
Quaking aspen	280	--	--	--	--	158	122
Paper birch	36	--	--	--	--	36	--
Black cherry	887	--	87	--	--	263	537
Other hardwoods	657	--	--	--	--	329	328
Total	7,579	61	87	--	--	2,388	5,043
All species	8,631	810	226	--	--	2,451	5,144

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[1] Tables may not add to totals due to rounding.

[2] Thinning was a treatment option only in the forest types shown below.

Table 13.--Average annual yields of growing stock from thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

Forest type	All ages	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS									
Red pine	13,772	--	6,370	6,208	1,194	--	--	--	--
White pine	226	--	--	--	226	--	--	--	--
White spruce	613	--	--	--	613	--	--	--	--
Oak-hickory	6,627	--	258	2,548	3,821	--	--	--	--
Maple-birch	105,706	--	2,411	8,405	32,623	30,131	19,446	12,690	--
All types	126,944	--	9,039	17,161	38,477	30,131	19,446	12,690	--
EASTERN UPPER PENINSULA									
Red pine	1,086	--	687	295	104	--	--	--	--
White pine	--	--	--	--	--	--	--	--	--
White spruce	472	--	--	--	472	--	--	--	--
Oak-hickory	34	--	--	8	26	--	--	--	--
Maple-birch	22,293	--	724	1,653	6,635	4,767	6,150	2,364	--
All types	23,885	--	1,411	1,956	7,237	4,767	6,150	2,364	--
WESTERN UPPER PENINSULA									
Red pine	1,143	--	463	680	--	--	--	--	--
White spruce	141	--	--	--	141	--	--	--	--
Oak-hickory	440	--	58	142	240	--	--	--	--
Maple-birch	44,280	--	546	3,303	14,964	14,195	6,517	4,755	--
All types	46,004	--	1,067	4,125	15,345	14,195	6,517	4,755	--
NORTHERN LOWER PENINSULA									
Red pine	10,733	--	5,029	5,009	695	--	--	--	--
Oak-hickory	3,702	--	200	1,227	2,275	--	--	--	--
Maple-birch	33,989	--	620	2,618	10,332	9,990	6,004	4,425	--
All types	48,424	--	5,849	8,854	13,302	9,990	6,004	4,425	--
SOUTHERN LOWER PENINSULA									
Red pine	810	--	191	224	395	--	--	--	--
White pine	226	--	--	--	226	--	--	--	--
Oak-hickory	2,451	--	--	1,171	1,280	--	--	--	--
Maple-birch	5,144	--	521	831	692	1,179	775	1,146	--
All types	8,631	--	712	2,226	2,593	1,179	775	1,146	--

[1] Tables may not add to totals due to rounding.

Table 14.--Commercial forest area qualifying for timber stand improvement by forest type, stand-age class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand acres)

Forest type	All ages	Stand-age class (years)								
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS										
Jack pine	59.7	10.5	29.3	19.9	--	--	--	--	--	--
Red pine	1.7	--	--	1.7	--	--	--	--	--	--
White pine	19.7	--	8.4	11.4	--	--	--	--	--	--
White spruce	20.9	--	5.9	--	15.0	--	--	--	--	--
Balsam fir	24.9	--	--	--	24.9	--	--	--	--	--
Northern white-cedar	48.0	--	--	--	--	48.0	--	--	--	--
Oak-hickory	20.1	--	--	4.5	5.4	10.2	--	--	--	--
Maple-birch	732.2	3.3	7.3	83.8	98.2	189.8	182.3	85.3	82.2	--
All types	927.1	13.8	50.8	121.2	143.3	248.0	182.3	85.3	82.2	--
EASTERN UPPER PENINSULA										
Jack pine	5.8	1.7	1.9	2.3	--	--	--	--	--	--
White pine	4.8	--	1.7	3.2	--	--	--	--	--	--
White spruce	3.2	--	3.2	--	--	--	--	--	--	--
Balsam fir	16.5	--	--	--	16.5	--	--	--	--	--
Northern white-cedar	25.8	--	--	--	--	25.8	--	--	--	--
Maple-birch	120.0	--	--	12.6	26.1	30.8	20.3	13.3	16.9	--
All types	176.1	1.7	6.7	18.1	42.5	56.6	20.3	13.3	16.9	--
WESTERN UPPER PENINSULA										
Jack pine	1.7	--	--	1.7	--	--	--	--	--	--
White spruce	12.4	--	--	--	12.4	--	--	--	--	--
Balsam fir	8.4	--	--	--	8.4	--	--	--	--	--
Northern white-cedar	8.8	--	--	--	--	8.8	--	--	--	--
Maple-birch	282.8	--	--	29.1	43.6	66.8	84.2	21.2	38.0	--
All types	314.1	--	--	30.8	64.3	75.6	84.2	21.2	38.0	--
NORTHERN LOWER PENINSULA										
Jack pine	52.2	8.8	27.4	15.9	--	--	--	--	--	--
Red pine	1.7	--	--	1.7	--	--	--	--	--	--
White pine	12.0	--	6.7	5.3	--	--	--	--	--	--
White spruce	2.7	--	2.7	--	--	--	--	--	--	--
Northern white-cedar	13.4	--	--	--	--	13.4	--	--	--	--
Oak-hickory	16.7	--	--	4.5	2.0	10.2	--	--	--	--
Maple-birch	228.7	--	--	23.6	21.9	65.4	70.3	27.3	20.1	--
All types	327.3	8.8	36.8	50.9	23.9	89.0	70.3	27.3	20.1	--
SOUTHERN LOWER PENINSULA										
White pine	2.9	--	--	2.9	--	--	--	--	--	--
White spruce	2.6	--	--	--	2.6	--	--	--	--	--
Oak-hickory	3.4	--	--	--	3.4	--	--	--	--	--
Maple-birch	100.7	3.3	7.3	18.5	6.6	26.8	7.5	23.5	7.2	--
All types	109.6	3.3	7.3	21.4	12.6	26.8	7.5	23.5	7.2	--

[1] Tables may not add to totals due to rounding.

Table 15.--Average annual yields from timber stand improvement by species group, tree class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

ALL UNITS

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	201	93	108	7	7	--
Red pine	273	--	273	--	--	--
White pine	351	47	304	27	9	18
White spruce	330	--	330	12	12	--
Balsam fir	705	495	210	6	--	6
Hemlock	31	13	18	8	8	--
Tamarack	9	9	--	--	--	--
Northern white-cedar	52	27	25	--	--	--
Other softwoods	433	372	61	83	--	83
Total	2,385	1,056	1,329	143	36	107
HARDWOODS						
White oak	18	--	18	--	--	--
Select red oak	154	--	154	--	--	--
Other red oak	42	--	42	--	--	--
Basswood	16	--	16	--	--	--
Hard maple	58	13	45	--	--	--
Soft maple	159	146	13	--	--	--
Elm	79	15	64	34	--	34
Ash	142	--	142	--	--	--
Balsam poplar	344	97	247	18	10	8
Bigtooth aspen	165	30	135	--	--	--
Quaking aspen	2,095	819	1,276	98	8	90
Other hardwoods	30	--	30	--	--	--
Total	3,302	1,120	2,182	150	18	132
All species	5,687	2,176	3,511	293	54	239
EASTERN UPPER PENINSULA						
SOFTWOODS						
Red pine	59	--	59	--	--	--
White pine	207	--	207	18	--	18
White spruce	136	--	136	--	--	--
Balsam fir	403	254	149	6	--	6
Hemlock	20	13	7	--	--	--
Northern white-cedar	11	--	11	--	--	--
Total	836	267	569	24	--	24
HARDWOODS						
Soft maple	82	69	13	--	--	--
Balsam poplar	244	60	184	10	10	--
Bigtooth aspen	61	15	46	--	--	--
Quaking aspen	887	274	613	13	8	5
Total	1,274	418	856	23	18	5
All species	2,110	685	1,425	47	18	29

(Table 15 continued on next page)

(Table 15 continued)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
	WESTERN UPPER PENINSULA					
SOFTWOODS						
White pine	66	47	19	--	--	--
White spruce	164	--	164	--	--	--
Balsam fir	110	90	20	--	--	--
Hemlock	11	--	11	8	8	--
Tamarack	9	9	--	--	--	--
Total	360	146	214	8	8	--
HARDWOODS						
Basswood	16	--	16	--	--	--
Hard maple	28	13	15	--	--	--
Elm	79	15	64	34	--	34
Balsam poplar	86	37	49	--	--	--
Quaking aspen	1,110	476	634	73	--	73
Total	1,319	541	778	107	--	107
All species	1,679	687	992	115	8	107
	NORTHERN LOWER PENINSULA					
SOFTWOODS						
Jack pine	201	93	108	7	7	--
Red pine	214	--	214	--	--	--
White pine	78	--	78	9	9	--
Balsam fir	192	151	41	--	--	--
Northern white-cedar	41	27	14	--	--	--
Other softwoods	433	372	61	83	--	83
Total	1,159	643	516	99	16	83
HARDWOODS						
White oak	18	--	18	--	--	--
Select red oak	102	--	102	--	--	--
Other red oak	42	--	42	--	--	--
Soft maple	77	77	--	--	--	--
Balsam poplar	14	--	14	8	--	8
Bigtooth aspen	104	15	89	--	--	--
Quaking aspen	69	69	--	--	--	--
Total	426	161	265	8	--	8
All species	1,585	804	781	107	16	91
	SOUTHERN LOWER PENINSULA					
SOFTWOODS						
White spruce	30	--	30	12	12	--
Total	30	--	30	12	12	--
HARDWOODS						
Select red oak	52	--	52	--	--	--
Hard maple	30	--	30	--	--	--
Ash	142	--	142	--	--	--
Quaking aspen	29	--	29	12	--	12
Other hardwoods	30	--	30	--	--	--
Total	283	--	283	12	--	12
All species	313	--	313	24	12	12

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 16.--Average annual yields of growing stock from timber stand improvement by species group, forest type, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

ALL UNITS

Species group	All types	Forest type[2] Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak-hickory	Maple-birch
SOFTWOODS									
Jack pine	201	201	--	--	--	--	--	--	--
Red pine	273	221	--	52	--	--	--	--	--
White pine	351	75	--	210	66	--	--	--	--
White spruce	330	--	--	--	188	142	--	--	--
Balsam fir	705	--	--	25	10	44	626	--	--
Hemlock	31	--	--	--	--	--	--	--	31
Tamarack	9	--	--	--	9	--	--	--	--
Northern white-cedar	52	--	--	52	--	--	--	--	--
Other softwoods	433	--	--	433	--	--	--	--	--
Total	2,385	497	--	772	273	186	626	--	31
HARDWOODS									
White oak	18	--	--	18	--	--	--	--	--
Select red oak	154	102	--	52	--	--	--	--	--
Other red oak	42	42	--	--	--	--	--	--	--
Basswood	16	--	--	--	--	--	--	--	16
Hard maple	58	--	--	--	--	--	--	--	58
Soft maple	159	--	--	159	--	--	--	--	--
Elm	79	--	--	--	--	49	--	--	30
Ash	142	--	--	--	--	--	--	--	142
Balsam poplar	344	--	--	10	--	59	275	--	--
Bigtooth aspen	165	--	--	--	--	--	165	--	--
Quaking aspen	2,095	--	--	193	1,011	779	68	--	44
Other hardwoods	30	--	--	--	--	--	--	--	30
Total	3,302	144	--	432	1,011	887	508	--	320
All species	5,687	641	--	1,204	1,284	1,073	1,134	--	351
EASTERN UPPER PENINSULA									
SOFTWOODS									
Red pine	59	59	--	--	--	--	--	--	--
White pine	207	75	--	132	--	--	--	--	--
White spruce	136	--	--	--	136	--	--	--	--
Balsam fir	403	--	--	13	--	--	390	--	--
Hemlock	20	--	--	--	--	--	--	--	20
Northern white-cedar	11	--	--	11	--	--	--	--	--
Total	836	134	--	156	136	--	390	--	20
HARDWOODS									
Soft maple	82	--	--	82	--	--	--	--	--
Balsam poplar	244	--	--	10	--	59	175	--	--
Bigtooth aspen	61	--	--	--	--	--	61	--	--
Quaking aspen	887	--	--	94	--	747	46	--	--
Total	1,274	--	--	186	--	806	282	--	--
All species	2,110	134	--	342	136	806	672	--	20

(Table 16 continued on next page)

(Table 16 continued)

		Forest type[2]							
Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak-hickory	Maple-birch
WESTERN UPPER PENINSULA									
SOFTWOODS									
White pine	66	--	--	--	66	--	--	--	--
White spruce	164	--	--	--	22	142	--	--	--
Balsam fir	110	--	--	12	10	44	44	--	--
Hemlock	11	--	--	--	--	--	--	--	11
Tamarack	9	--	--	--	9	--	--	--	--
Total	360	--	--	12	107	186	44	--	11
HARDWOODS									
Basswood	16	--	--	--	--	--	--	--	16
Hard maple	28	--	--	--	--	--	--	--	28
Elm	79	--	--	--	--	49	--	--	30
Balsam poplar	86	--	--	--	--	--	86	--	--
Quaking aspen	1,110	--	--	80	974	32	9	--	15
Total	1,319	--	--	80	974	81	95	--	89
All species	1,679	--	--	92	1,081	267	139	--	100
NORTHERN LOWER PENINSULA									
SOFTWOODS									
Jack pine	201	201	--	--	--	--	--	--	--
Red pine	214	162	--	52	--	--	--	--	--
White pine	78	--	--	78	--	--	--	--	--
Balsam fir	192	--	--	--	-	--	192	--	--
Northern white-cedar	41	--	--	41	--	--	--	--	--
Other softwoods	433	--	--	433	--	--	--	--	--
Total	1,159	363	--	604	--	--	192	--	--
HARDWOODS									
White oak	18	--	--	18	--	--	--	--	--
Select red oak	102	102	--	--	--	--	--	--	--
Other red oak	42	42	--	--	--	--	--	--	--
Soft maple	77	--	--	77	--	--	--	--	--
Balsam poplar	14	--	--	--	--	--	14	--	--
Bigtooth aspen	104	--	--	--	--	--	104	--	--
Quaking aspen	69	--	--	19	37	--	13	--	--
Total	426	144	--	114	37	--	131	--	--
All species	1,585	507	--	718	37	--	323	--	--
SOUTHERN LOWER PENINSULA									
SOFTWOODS									
White spruce	30	--	--	--	30	--	--	--	--
Total	30	--	--	--	30	--	--	--	--
HARDWOODS									
Select red oak	52	--	--	52	--	--	--	--	--
Hard maple	30	--	--	--	--	--	--	--	30
Ash	142	--	--	--	--	--	--	--	142
Quaking aspen	29	--	--	--	--	--	--	--	29
Other hardwoods	30	--	--	--	--	--	--	--	30
Total	283	--	--	52	--	--	--	--	231
All species	313	--	--	52	30	--	--	--	231

[1] Tables may not add to totals due to rounding.

[2] Timber stand improvement was a treatment option only in the forest types shown below.

Table 17.--Average annual yields of growing stock from timber stand improvement by forest type, stand age class, and Forest Survey Unit, Michigan, 1981-1990[1]

(In thousand cubic feet)

		Stand-age class (years)					
Forest type	All ages	1-10	11-20	21-30	31-40	41-50	51+
ALL UNITS							
Jack pine	641	134	360	147	--	--	--
White pine	1,204	--	368	836	--	--	--
White spruce	1,284	--	173	--	1,111	--	--
Balsam fir	1,073	--	--	--	1,073	--	--
Northern white-cedar	1,134	--	--	--	--	1,134	--
Maple-birch	351	142	89	100	20	--	--
All types	5,687	276	990	1,083	2,204	1,134	--
EASTERN UPPER PENINSULA							
Jack pine	134	58	33	43	--	--	--
White pine	342	--	83	259	--	--	--
White spruce	136	--	136	--	--	--	--
Balsam fir	806	--	--	--	806	--	--
Northern white-cedar	672	--	--	--	--	672	--
Maple-birch	20	--	--	--	20	--	--
All types	2,110	58	252	302	826	672	--
WESTERN UPPER PENINSULA							
White pine	92	--	--	92	--	--	--
White spruce	1,081	--	--	--	1,081	--	--
Balsam fir	267	--	--	--	267	--	--
Northern white-cedar	139	--	--	--	--	139	--
Maple-birch	100	--	--	100	--	--	--
All types	1,679	--	--	192	1,348	139	--
NORTHERN LOWER PENINSULA							
Jack pine	507	76	327	104	--	--	--
White pine	718	--	285	433	--	--	--
White spruce	37	--	37	--	--	--	--
Northern white-cedar	323	--	--	--	--	323	--
All types	1,585	76	649	537	--	323	--
SOUTHERN LOWER PENINSULA							
White pine	52	--	--	52	--	--	--
White spruce	30	--	--	--	30	--	--
Maple-birch	231	142	89	--	--	--	--
All types	313	142	89	52	30	--	--

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[1] Tables may not add to totals due to rounding.

Table 18.--Commercial forest area qualifying for treatment and average annual yields of growing stock from each treatment by treatment category and Survey Unit, Michigan, 1991-2000[1]

		Forest Survey Unit			
Treatment	All units	Eastern Upper Peninsula	Western Upper Peninsula	Northern Lower Peninsula	Southern Lower Peninsula
COMMERCIAL FOREST AREA					
		In thousand acres			
Harvest	2,531.0	550.4	640.5	1,045.5	294.6
Thinning	2,636.8	488.3	981.4	915.9	251.2
Timber stand improvement	448.6	109.6	123.9	137.2	77.9
No treatment	11,654.5	2,576.3	2,701.5	4,598.5	1,778.2
Total	17,270.9	3,724.6	4,447.3	6,697.1	2,401.9
AVERAGE ANNUAL YIELDS OF GROWING STOCK					
		In thousand cubic feet			
Harvest	528,393	108,595	141,816	214,010	63,972
Thinning	136,546	22,971	47,351	55,305	10,919
Timber stand improvement	2,015	1,022	381	612	--
Total	666,954	132,588	189,548	269,927	74,891

[1] Tables may not add to totals due to rounding.

Table 19.--Commercial forest area qualifying for harvest by forest type, stand-age class, and Forest Survey Unit, Michigan, 1991-2000[1/]

(In thousand acres)

ALL UNITS

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	149.0	--	--	--	104.2	43.2	1.6	--	--	--	--	--
Red pine	109.3	--	--	62.4	37.4	--	4.8	1.3	3.2	0.2	--	--
White pine	25.5	--	--	--	--	--	0.3	2.0	--	13.7	9.6	--
White spruce	13.0	--	--	1.1	--	1.5	2.1	4.8	2.2	--	1.4	--
Black spruce	65.4	--	--	--	18.4	18.4	20.8	7.8	--	--	--	--
Balsam fir	110.9	--	--	--	17.9	33.9	35.4	19.0	4.7	--	--	--
Tamarack	13.8	--	--	--	--	5.8	5.0	1.7	--	1.3	--	--
Northern white-cedar	147.1	--	--	--	--	--	--	1.0	--	45.1	97.2	3.9
Oak-hickory	229.0	--	--	--	--	--	0.4	58.0	94.2	40.9	35.5	--
Elm-ash-maple	151.1	--	--	--	--	--	--	33.2	70.1	24.9	17.8	5.2
Maple-birch	674.3	--	--	--	--	--	--	53.7	181.7	77.8	361.2	--
Aspen	760.2	--	--	72.3	406.0	281.9	--	--	--	--	--	--
Paper birch	68.5	--	--	1.1	--	4.0	60.3	3.2	--	--	--	--
Exotic	13.8	--	9.2	4.6	--	--	--	--	--	--	--	--
All types	2,531.1	--	9.2	141.5	583.8	388.6	130.7	185.5	356.1	203.8	522.7	9.1
EASTERN UPPER PENINSULA												
Jack pine	37.0	--	--	--	30.8	6.1	--	--	--	--	--	--
Red pine	24.6	--	--	14.3	10.3	--	--	--	--	--	--	--
White pine	8.2	--	--	--	--	--	--	--	--	1.3	6.9	--
White spruce	3.7	--	--	--	--	--	0.4	2.8	0.5	--	--	--
Black spruce	34.8	--	--	--	18.4	16.4	--	--	--	--	--	--
Balsam fir	37.3	--	--	--	17.9	19.5	--	--	--	--	--	--
Tamarack	5.5	--	--	--	--	0.5	3.3	1.7	--	--	--	--
Northern white-cedar	76.5	--	--	--	--	--	--	--	--	28.2	48.3	--
Oak-hickory	2.5	--	--	--	--	--	0.4	--	1.5	0.6	--	--
Elm-ash-maple	21.7	--	--	--	--	--	--	--	6.1	13.2	2.4	--
Maple-birch	125.8	--	--	--	--	--	--	--	--	33.8	92.0	--
Aspen	150.8	--	--	--	117.4	33.4	--	--	--	--	--	--
Paper birch	21.5	--	--	--	--	3.8	17.7	--	--	--	--	--
Exotic	0.4	--	0.4	--	--	--	--	--	--	--	--	--
All types	550.4	--	0.4	14.3	194.8	79.7	21.8	4.5	8.1	77.1	149.7	--

(Table 19 continued on next page)

(Table 19 continued)

Forest type	All ages	1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
		Stand-age class (years)										
WESTERN UPPER PENINSULA												
Jack pine	14.8	--	--	--	--	14.8	--	--	--	--	--	--
Red pine	9.5	--	--	--	--	--	4.8	1.3	3.2	0.2	--	--
White pine	5.1	--	--	--	--	--	--	--	--	2.5	2.7	--
White spruce	6.6	--	--	--	--	1.5	1.7	2.0	--	--	1.4	--
Black spruce	27.5	--	--	--	--	0.8	18.9	7.8	--	--	--	--
Balsam fir	67.3	--	--	--	--	14.4	35.4	17.5	--	--	--	--
Tamarack	5.1	--	--	--	--	3.4	0.3	--	--	1.3	--	--
Northern white-cedar	25.3	--	--	--	--	--	--	--	--	--	21.4	3.9
Oak-hickory	2.2	--	--	--	--	--	--	--	--	--	2.2	--
Elm-ash-maple	20.6	--	--	--	--	--	--	--	--	--	15.4	5.2
Maple-birch	269.2	--	--	--	--	--	--	--	--	--	269.2	--
Aspen	159.5	--	--	--	60.4	99.1	--	--	--	--	--	--
Paper birch	27.9	--	--	--	--	0.2	24.6	3.2	--	--	--	--
All types	640.5	--	--	--	60.4	134.1	85.8	31.7	3.2	4.0	312.2	9.1
NORTHERN LOWER PENINSULA												
Jack pine	94.8	--	--	--	72.5	22.3	--	--	--	--	--	--
Red pine	70.7	--	--	48.2	22.6	--	--	--	--	--	--	--
White pine	9.9	--	--	--	--	--	--	--	--	9.9	--	--
White spruce	1.7	--	--	--	--	--	--	--	1.7	--	--	--
Black spruce	3.1	--	--	--	--	1.1	1.9	--	--	--	--	--
Balsam fir	6.2	--	--	--	--	--	--	1.5	4.7	--	--	--
Tamarack	3.2	--	--	--	--	1.9	1.3	--	--	--	--	--
Northern white-cedar	44.4	--	--	--	--	--	--	--	--	16.9	27.5	--
Oak-hickory	136.5	--	--	--	--	--	--	58.0	68.9	9.6	--	--
Elm-ash-maple	42.9	--	--	--	--	--	--	12.8	22.3	7.8	--	--
Maple-birch	189.1	--	--	--	--	--	--	53.7	132.3	3.1	--	--
Aspen	416.5	--	--	49.2	217.8	149.4	--	--	--	--	--	--
Paper birch	18.0	--	--	--	--	--	18.0	--	--	--	--	--
Exotic	8.5	--	7.0	1.5	--	--	--	--	--	--	--	--
All types	1,045.5	--	7.0	98.8	312.9	174.8	21.3	126.0	229.9	47.4	27.5	--
SOUTHERN LOWER PENINSULA												
Jack pine	2.5	--	--	--	0.9	--	1.6	--	--	--	--	--
Red pine	4.5	--	--	--	4.5	--	--	--	--	--	--	--
White pine	2.2	--	--	--	--	--	0.3	2.0	--	--	--	--
White spruce	1.1	--	--	1.1	--	--	--	--	--	--	--	--
Northern white-cedar	1.0	--	--	--	--	--	--	1.0	--	--	--	--
Oak-hickory	87.8	--	--	--	--	--	--	--	23.8	30.6	33.4	--
Elm-ash-maple	65.9	--	--	--	--	--	--	20.4	41.7	3.8	--	--
Maple-birch	90.2	--	--	--	--	--	--	--	49.4	40.8	--	--
Aspen	33.4	--	--	23.1	10.3	--	--	--	--	--	--	--
Paper birch	1.1	--	--	1.1	--	--	--	--	--	--	--	--
Exotic	5.0	--	1.8	3.2	--	--	--	--	--	--	--	--
All types	294.6	--	1.8	28.5	15.7	--	1.9	23.3	114.9	75.3	33.4	--

[1] Tables may not add to totals due to rounding.

Table 20.--Average annual yields from harvest by species group, tree class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
			ALL UNITS			
SOFTWOODS						
Jack pine	21,795	8,336	13,459	453	66	387
Red pine	28,810	4,607	24,203	160	36	124
White pine	17,488	1,193	16,295	372	96	276
White spruce	16,673	2,325	14,348	133	24	109
Black spruce	8,607	6,606	2,001	51	--	51
Balsam fir	28,486	14,921	13,565	283	36	247
Hemlock	12,445	1,073	11,372	701	265	436
Tamarack	1,398	606	792	25	11	14
Northern white-cedar	33,567	14,210	19,357	3,401	616	2,785
Other softwoods	1,275	1,014	261	77	--	77
Total	170,544	54,891	115,653	5,656	1,150	4,506
HARDWOODS						
White oak	14,463	1,639	12,824	673	213	460
Select red oak	27,453	2,387	25,066	1,247	295	952
Other red oak	6,579	898	5,681	269	95	174
Hickory	2,542	374	2,168	87	60	27
Basswood	11,959	1,050	10,909	442	143	299
Beech	6,256	1,198	5,058	920	215	705
Yellow birch	8,912	1,637	7,275	1,488	421	1,067
Hard maple	57,302	12,012	45,290	3,668	974	2,694
Soft maple	70,620	17,299	53,321	4,227	957	3,270
Elm	4,472	1,242	3,230	219	68	151
Ash	10,023	3,199	6,824	387	72	315
Cottonwood	277	--	277	--	--	--
Balsam poplar	8,846	894	7,952	292	10	282
Bigtooth aspen	36,744	6,579	30,165	1,851	280	1,571
Quaking aspen	58,289	9,903	48,386	3,424	331	3,093
Paper birch	22,628	8,438	14,190	1,254	80	1,174
Black cherry	8,007	1,647	6,360	627	187	440
Other hardwoods	2,477	481	1,996	147	37	110
Total	357,849	70,877	286,972	21,222	4,438	16,784
All species	528,393	125,768	402,625	26,878	5,588	21,290
			EASTERN UPPER PENINSULA			
SOFTWOODS						
Jack pine	5,932	2,763	3,169	64	4	60
Red pine	6,104	1,080	5,024	32	--	32
White pine	4,045	150	3,895	146	10	136
White spruce	5,704	733	4,971	51	--	51
Black spruce	4,126	3,304	822	7	--	7
Balsam fir	10,526	6,222	4,304	118	12	106
Hemlock	3,681	371	3,310	209	47	162
Tamarack	707	303	404	14	11	3
Northern white-cedar	13,937	6,144	7,793	925	92	833
Other softwoods	69	37	32	1	--	1
Total	54,831	21,107	33,724	1,567	176	1,391
HARDWOODS						
White oak	4	--	4	--	--	--
Select red oak	413	50	363	111	3	108
Basswood	918	116	802	122	69	53
Beech	2,611	388	2,223	472	89	383
Yellow birch	1,824	219	1,605	304	57	247
Hard maple	9,088	1,800	7,288	411	93	318
Soft maple	12,314	3,222	9,092	1,123	145	978
Elm	443	105	338	36	--	36
Ash	1,021	584	437	84	15	69
Balsam poplar	3,771	469	3,302	72	10	62
Bigtooth aspen	1,609	504	1,105	81	--	81
Quaking aspen	12,057	2,847	9,210	697	72	625
Paper birch	6,988	2,799	4,189	435	7	428
Black cherry	690	126	564	113	18	95
Other hardwoods	13	--	13	--	--	--
Total	53,764	13,229	40,535	4,061	578	3,483
All species	108,595	34,336	74,259	5,628	754	4,874

(Table 20 continued on next page)

(Table 20 continued)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
WESTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	2,377	375	2,002	43	--	43
Red pine	2,409	236	2,173	23	21	2
White pine	3,640	69	3,571	83	16	67
White spruce	10,330	1,341	8,989	69	24	45
Black spruce	3,792	2,765	1,027	35	--	35
Balsam fir	14,495	7,241	7,254	118	24	94
Hemlock	6,926	260	6,666	446	198	248
Tamarack	482	203	279	4	--	4
Northern white-cedar	7,140	1,735	5,405	1,083	208	875
Other softwoods	13	--	13	6	--	6
Total	51,604	14,225	37,379	1,910	491	1,419
HARDWOODS						
Select red oak	1,304	184	1,120	49	9	40
Basswood	2,911	400	2,511	88	27	61
Yellow birch	6,241	1,172	5,069	1,097	332	765
Hard maple	27,806	5,721	22,085	2,362	560	1,802
Soft maple	16,029	4,893	11,136	1,419	293	1,126
Elm	2,237	377	1,860	101	46	55
Ash	1,351	424	927	67	5	62
Balsam poplar	1,687	129	1,558	2	--	2
Bigtooth aspen	4,342	665	3,677	306	89	217
Quaking aspen	18,161	2,713	15,448	1,285	190	1,095
Paper birch	6,527	1,905	4,622	471	46	425
Black cherry	1,616	497	1,119	148	--	148
Total	90,212	19,080	71,132	7,395	1,597	5,798
All species	141,816	33,305	108,511	9,305	2,088	7,217
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	13,017	5,062	7,955	346	62	284
Red pine	19,083	3,187	15,896	24	14	10
White pine	6,871	818	6,053	30	30	--
White spruce	580	221	359	13	--	13
Black spruce	689	537	152	9	--	9
Balsam fir	3,465	1,458	2,007	47	--	47
Hemlock	1,647	387	1,260	46	20	26
Tamarack	209	100	109	7	--	7
Northern white-cedar	12,428	6,316	6,112	1,393	316	1,077
Other softwoods	796	735	61	52	--	52
Total	58,785	18,821	39,964	1,967	442	1,525
HARDWOODS						
White oak	6,293	1,113	5,180	266	89	177
Select red oak	17,926	1,740	16,186	853	225	628
Other red oak	4,300	778	3,522	192	18	174
Basswood	5,707	442	5,265	128	37	91
Beech	2,347	547	1,800	432	126	306
Yellow birch	719	219	500	50	8	42
Hard maple	17,596	4,176	13,420	801	321	480
Soft maple	27,515	7,107	20,408	1,123	307	816
Elm	878	290	588	41	22	19
Ash	4,576	1,223	3,353	107	25	82
Cottonwood	105	--	105	--	--	--
Balsam poplar	3,203	292	2,911	218	--	218
Bigtooth aspen	28,571	4,991	23,580	1,440	191	1,249
Quaking aspen	25,101	3,677	21,424	1,258	69	1,189
Paper birch	8,210	3,149	5,061	348	27	321
Black cherry	2,064	391	1,673	182	22	160
Other hardwoods	114	52	62	--	--	--
Total	155,225	30,187	125,038	7,439	1,487	5,952
All species	214,010	49,008	165,002	9,406	1,929	7,477

(Table 20 continued on next page)

(Table 20 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	469	136	333	—	—	--
Red pine	1,214	104	1,110	81	1	80
White pine	2,932	156	2,776	113	40	73
White spruce	59	30	29	--	--	--
Hemlock	191	55	136	—	--	--
Northern white-cedar	62	15	47	—	--	—
Other softwoods	397	242	155	18	--	18
Total	5,324	738	4,586	212	41	171
HARDWOODS						
White oak	8,166	526	7,640	407	124	283
Select red oak	7,810	413	7,397	234	58	176
Other red oak	2,279	120	2,159	77	77	—
Hickory	2,542	374	2,168	87	60	27
Basswood	2,423	92	2,331	104	10	94
Beech	1,298	263	1,035	16	--	16
Yellow birch	128	27	101	37	24	13
Hard maple	2,812	315	2,497	94	--	94
Soft maple	14,762	2,077	12,685	562	212	350
Elm	914	470	444	41	--	41
Ash	3,075	968	2,107	129	27	102
Cottonwood	172	--	172	--	--	--
Balsam poplar	185	4	181	--	--	--
Bigtooth aspen	2,222	419	1,803	24	--	24
Quaking aspen	2,970	666	2,304	184	--	184
Paper birch	903	585	318	--	--	--
Black cherry	3,637	633	3,004	184	147	37
Other hardwoods	2,350	429	1,921	147	37	110
Total	58,648	8,381	50,267	2,327	776	1,551
All species	63,972	9,119	54,853	2,539	817	1,722

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 21.--Average annual yields of growing stock from harvest by species group, forest type, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

ALL UNITS

Species group	All types	Forest type Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	21,795	17,131	2,376	151	4	149	20	43	--	730	--	64	1,127	--	--
Red pine	28,810	2,543	19,664	458	22	147	229	--	--	933	--	1,157	3,032	62	563
White pine	17,488	469	848	5,113	139	380	898	--	1,055	715	301	4,845	2,541	184	--
White spruce	16,673	--	--	170	2,011	303	3,520	--	641	7	504	2,586	5,905	1,006	20
Black spruce	8,607	150	32	75	7	5,031	907	258	910	--	81	112	975	69	--
Balsam fir	28,486	--	161	25	277	867	9,087	211	2,033	--	865	3,737	10,277	946	--
Hemlock	12,445	--	--	108	--	10	222	--	307	153	785	10,444	370	46	--
Tamarack	1,398	--	--	11	--	264	32	749	89	--	72	--	176	5	--
Northern white-cedar	33,567	--	--	20	222	777	1,539	134	20,409	--	1,755	3,666	4,015	1,030	--
Other softwoods	1,275	--	--	--	74	--	14	--	--	--	--	13	--	--	1,174
Total	170,544	20,293	23,081	6,131	2,756	7,928	16,468	1,395	25,444	2,538	4,363	26,624	28,418	3,348	1,757
HARDWOODS															
White oak	14,463	63	48	369	--	--	--	--	--	10,358	1,269	1,521	835	--	--
Select red oak	27,453	1,632	290	283	--	--	--	--	--	16,444	740	3,458	4,393	123	90
Other red oak	6,579	295	451	--	--	--	--	--	--	4,779	--	460	594	--	--
Hickory	2,542	10	--	--	--	--	--	--	--	1,280	164	1,088	--	--	--
Basswood	11,959	48	--	--	--	--	--	--	32	182	751	9,899	872	160	15
Beech	6,256	--	--	--	--	--	--	--	--	74	118	5,544	520	--	--
Yellow birch	8,912	--	--	6	10	24	388	--	272	5	848	6,909	410	40	--
Hard maple	57,302	27	--	119	70	--	292	--	--	163	723	52,522	2,958	400	28
Soft maple	70,620	133	237	185	140	122	2,319	--	1,172	3,569	17,816	25,274	18,287	1,366	--
Elm	4,472	23	--	--	--	--	225	--	--	162	664	2,329	1,020	49	--
Ash	10,023	--	9	--	--	34	57	13	334	214	3,518	3,808	1,798	229	9
Cottonwood	277	--	--	--	--	--	--	--	--	37	--	73	167	--	--
Balsam poplar	8,846	--	--	--	124	15	369	56	589	--	337	269	6,985	102	--
Bigtooth aspen	36,744	188	372	9	--	--	168	--	--	2,499	206	1,994	31,144	164	--
Quaking aspen	58,289	688	368	118	249	429	1,336	35	337	622	640	4,211	48,145	1,044	67
Paper birch	22,628	15	169	130	4	655	1,457	85	1,119	494	137	2,093	9,837	6,433	--
Black cherry	8,007	16	--	--	40	17	175	--	14	1,058	386	4,982	1,127	--	192
Other hardwoods	2,477	11	--	--	--	--	--	--	13	485	988	948	32	--	--
Total	357,849	3,149	1,944	1,219	637	1,296	6,786	189	3,882	42,425	29,305	127,382	129,124	10,110	401
All species	528,393	23,442	25,025	7,350	3,393	9,224	23,254	1,584	29,326	44,963	33,668	154,006	157,542	13,458	2,158

(Table 21 continued on next page)

(Table 21 continued)

EASTERN UPPER PENINSULA

Species group	All types	Forest type: Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	5,932	4,344	958	7	4	104	--	--	--	--	--	--	615	--	--
Red pine	6,104	766	4,563	121	22	129	--	--	--	19	--	16	453	--	15
White pine	4,045	--	89	1,173	20	343	379	--	443	37	150	935	443	33	--
White spruce	5,704	--	--	101	572	126	790	--	336	7	89	497	2,958	208	20
Black spruce	4,126	150	--	23	7	2,513	273	29	415	--	19	60	637	--	--
Balsam fir	10,526	--	--	15	81	356	2,734	37	1,066	--	300	1,014	4,493	430	--
Hemlock	3,681	--	--	44	--	10	67	--	197	--	380	2,871	66	46	--
Tamarack	707	--	--	11	--	83	32	442	35	--	--	--	104	--	--
Northern white-cedar	13,937	--	--	20	123	396	535	17	10,237	--	669	716	963	261	--
Other softwoods	69	--	--	--	--	--	14	--	--	--	--	--	--	--	55
Total	54,831	5,260	5,510	1,515	829	4,060	4,824	525	12,729	63	1,607	6,109	10,732	978	90
HARDWOODS															
White oak	4	--	--	--	--	--	--	--	--	4	--	--	--	--	--
Select red oak	413	55	--	--	--	--	--	--	--	150	35	36	137	--	--
Basswood	918	--	--	--	--	--	--	--	--	41	--	751	126	--	--
Beech	2,611	--	--	--	--	--	--	--	--	--	31	2,580	--	--	--
Yellow birch	1,824	--	--	--	10	11	196	--	119	--	262	1,202	24	--	--
Hard maple	9,088	--	--	--	4	--	38	--	--	6	115	8,701	224	--	--
Soft maple	12,314	--	119	51	47	50	749	--	624	19	2,134	6,374	1,699	448	--
Elm	443	--	--	--	--	--	84	--	--	--	--	189	170	--	--
Ash	1,021	--	--	--	--	--	26	--	102	--	421	101	219	152	--
Balsam poplar	3,771	--	--	--	17	15	108	7	148	--	64	82	3,320	10	--
Bigtooth aspen	1,609	34	170	--	--	--	15	--	--	--	--	13	1,377	--	--
Quaking aspen	12,057	--	23	60	67	319	452	--	134	3	55	309	10,186	449	--
Paper birch	6,988	15	--	51	4	402	623	--	690	54	49	339	2,868	1,883	--
Black cherry	690	--	--	--	--	17	32	--	--	--	--	437	204	--	--
Other hardwoods	13	--	--	--	--	--	--	--	--	--	--	13	--	--	--
Total	53,764	104	312	172	149	814	2,323	7	1,817	277	3,166	21,127	20,554	2,942	--
All species	108,595	5,364	5,822	1,687	978	4,874	7,147	532	14,546	340	4,773	27,236	31,286	3,920	90

(Table 21 continued on next page)

(Table 21 continued)

WESTERN UPPER PENINSULA

Species group	All types	Forest type Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	2,377	2,198	45	53	--	45	20	--	--	--	--	--	16	--	--
Red pine	2,409	262	1,355	--	--	18	199	--	--	7	--	17	516	35	--
White pine	3,640	--	511	1,209	119	37	324	--	78	--	70	721	482	89	--
White spruce	10,330	--	--	69	1,290	177	2,730	--	129	--	370	2,053	2,758	754	--
Black spruce	3,792	--	32	10	--	2,239	634	141	215	--	62	52	338	69	--
Balsam fir	14,495	--	161	10	167	500	6,120	103	679	--	390	2,555	3,414	396	--
Hemlock	6,926	--	--	64	--	--	155	--	7	--	193	6,432	75	--	--
Tamarack	482	--	--	--	--	181	--	242	7	--	--	--	52	--	--
Northern white-cedar	7,140	--	--	--	35	381	854	102	2,678	--	426	2,037	459	168	--
Other softwoods	13	--	--	--	--	--	--	--	--	--	--	13	--	--	--
Total	51,604	2,460	2,104	1,415	1,611	3,578	11,036	588	3,793	7	1,511	13,880	8,110	1,511	--
HARDWOODS															
Select red oak	1,304	142	54	46	--	--	--	--	--	276	--	564	109	113	--
Basswood	2,911	--	--	--	--	--	--	--	--	--	78	2,601	232	--	--
Yellow birch	6,241	--	--	6	--	13	192	--	116	5	237	5,312	360	--	--
Hard maple	27,806	--	--	119	66	--	198	--	--	--	321	25,428	1,324	350	--
Soft maple	16,029	--	96	65	93	72	1,436	--	157	24	899	9,417	3,137	633	--
Elm	2,237	--	--	--	--	--	141	--	--	--	201	1,318	577	--	--
Ash	1,351	--	--	--	--	34	31	--	57	--	517	376	209	27	--
Balsam poplar	1,687	--	--	--	--	--	261	20	27	--	--	122	1,165	92	--
Bigtooth aspen	4,342	52	158	--	--	--	137	--	--	--	--	245	3,640	110	--
Quaking aspen	18,161	--	198	37	168	110	744	22	25	20	70	1,742	14,668	357	--
Paper birch	6,527	--	148	68	--	253	702	11	181	--	5	601	1,688	2,870	--
Black cherry	1,616	--	--	--	--	--	143	--	14	--	3	1,276	180	--	--
Total	90,212	194	654	341	327	482	3,985	53	577	325	2,431	49,002	27,289	4,552	--
All species	141,816	2,654	2,758	1,756	1,938	4,060	15,021	641	4,370	332	3,942	62,882	35,399	6,063	--

(Table 21 continued on next page)

(Table 21 continued)

NORTHERN LOWER PENINSULA

Species group	All types	Forest type: Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	13,017	10,208	1,437	91	--	--	--	43	--	678	--	64	496	--	--
Red pine	19,083	1,515	12,758	337	--	--	30	--	--	787	--	1,124	2,001	27	504
White pine	6,871	469	185	1,618	--	--	195	--	534	438	81	1,673	1,616	62	--
White spruce	580	--	--	--	90	--	--	--	176	--	45	36	189	44	--
Black spruce	689	--	--	42	--	279	--	88	280	--	--	--	--	--	--
Balsam fir	3,465	--	--	--	29	11	233	71	288	--	175	168	2,370	120	--
Hemlock	1,647	--	--	--	--	--	--	--	103	67	165	1,083	229	--	--
Tamarack	209	--	--	--	--	--	--	65	47	--	72	--	20	5	--
Northern white-cedar	12,428	--	--	--	64	--	150	15	7,432	--	660	913	2,593	601	--
Other softwoods	796	--	--	--	--	--	--	--	--	--	--	--	--	--	796
Total	58,785	12,192	14,380	2,088	183	290	608	282	8,860	1,970	1,198	5,061	9,514	859	1,300
HARDWOODS															
White oak	6,293	63	48	366	--	--	--	--	--	4,707	101	256	752	--	--
Select red oak	17,926	1,435	236	196	--	--	--	--	--	10,928	--	1,130	3,936	10	55
Other red oak	4,300	295	451	--	--	--	--	--	--	2,960	--	--	594	--	--
Basswood	5,707	48	--	--	--	--	--	--	32	--	301	4,759	514	38	15
Beech	2,347	--	--	--	--	--	--	--	--	22	24	1,816	485	--	--
Yellow birch	719	--	--	--	--	--	--	--	37	--	248	368	26	40	--
Hard maple	17,596	27	--	--	--	--	56	--	--	51	257	15,717	1,410	50	28
Soft maple	27,515	71	22	69	--	--	134	--	391	2,078	5,049	6,754	12,701	246	--
Elm	878	23	--	--	--	--	--	--	--	22	138	373	273	49	--
Ash	4,576	--	9	--	--	--	--	13	175	48	1,098	2,091	1,083	50	9
Cottonwood	105	--	--	--	--	--	--	--	--	--	--	33	72	--	--
Balsam poplar	3,203	--	--	--	107	--	--	29	414	--	101	65	2,487	--	--
Bigtooth aspen	28,571	102	44	9	--	--	16	--	--	1,992	22	1,552	24,780	54	--
Quaking aspen	25,101	688	147	21	14	--	140	13	172	282	353	1,930	21,114	227	--
Paper birch	8,210	--	21	1	--	--	132	74	248	371	40	1,120	4,582	1,621	--
Black cherry	2,064	16	--	--	--	--	--	--	--	105	100	1,314	501	--	28
Other hardwoods	114	--	--	--	--	--	--	--	--	52	--	30	32	--	--
Total	155,225	2,768	978	662	121	--	478	129	1,469	23,618	7,832	39,308	75,342	2,385	135
All species	214,010	14,960	15,358	2,750	304	290	1,086	411	10,329	25,588	9,030	44,369	84,856	3,244	1,435

(Table 21 continued on next page)

(Table 21 continued)

SOUTHERN LOWER PENINSULA

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	469	381	36	--	--	--	--	--	--	52	--	--	--	--	--
Red pine	1,214	--	988	--	--	--	--	--	--	120	--	--	62	--	44
White pine	2,932	--	63	1,113	--	--	--	--	--	240	--	1,516	--	--	--
White spruce	59	--	--	--	59	--	--	--	--	--	--	--	--	--	--
Hemlock	191	--	--	--	--	--	--	--	--	86	47	58	--	--	--
Northern white-cedar	62	--	--	--	--	--	--	--	62	--	--	--	--	--	--
Other softwoods	397	--	--	--	74	--	--	--	--	--	--	--	--	--	323
Total	5,324	381	1,087	1,113	133	--	--	--	62	498	47	1,574	62	--	367
HARDWOODS															
White oak	8,166	--	--	3	--	--	--	--	--	5,647	1,168	1,265	83	--	--
Select red oak	7,810	--	--	41	--	--	--	--	--	5,090	705	1,728	211	--	35
Other red oak	2,279	--	--	--	--	--	--	--	--	1,819	--	460	--	--	--
Hickory	2,542	10	--	--	--	--	--	--	--	1,280	164	1,088	--	--	--
Basswood	2,423	--	--	--	--	--	--	--	--	141	372	1,788	--	122	--
Beech	1,298	--	--	--	--	--	--	--	--	52	63	1,148	35	--	--
Yellow birch	128	--	--	--	--	--	--	--	--	--	101	27	--	--	--
Hard maple	2,812	--	--	--	--	--	--	--	--	106	30	2,676	--	--	--
Soft maple	14,762	62	--	--	--	--	--	--	--	1,448	9,734	2,729	750	39	--
Elm	914	--	--	--	--	--	--	--	--	140	325	449	--	--	--
Ash	3,075	--	--	--	--	--	--	--	--	166	1,382	1,240	287	--	--
Cottonwood	172	--	--	--	--	--	--	--	--	37	--	40	95	--	--
Balsam poplar	185	--	--	--	--	--	--	--	--	--	172	--	13	--	--
Bigtooth aspen	2,222	--	--	--	--	--	--	--	--	507	184	184	1,347	--	--
Quaking aspen	2,970	--	--	--	--	--	--	--	6	317	162	230	2,177	11	67
Paper birch	903	--	--	--	--	--	--	--	--	69	43	33	699	59	--
Black cherry	3,637	--	--	--	40	--	--	--	--	953	283	1,955	242	--	164
Other hardwoods	2,350	11	--	--	--	--	--	--	13	433	988	905	--	--	--
Total	58,648	83	--	44	40	--	--	--	19	18,205	15,876	17,945	5,939	231	266
All species	63,972	464	1,087	1,157	173	--	--	--	81	18,703	15,923	19,519	6,001	231	633

[1] Tables may not add to totals due to rounding.

Table 22.--Average annual yields of growing stock from harvest by forest type, stand-age class, and Forest Survey Unit, Michigan, 1991-2000[1]/

(In thousand cubic feet)

ALL UNITS

		Stand-age class (years)										
Forest type	All ages	1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	23,442	--	--	--	16,593	6,548	301	--	--	--	--	--
Red pine	25,025	--	--	14,146	8,121	--	1,463	310	953	32	--	--
White pine	7,350	--	--	--	--	--	101	1,056	--	3,863	2,330	--
White spruce	3,393	--	--	173	--	289	835	1,277	473	--	346	--
Black spruce	9,224	--	--	--	2,751	2,435	2,938	1,100	--	--	--	--
Balsam fir	23,254	--	--	--	3,819	6,638	8,085	3,827	885	--	--	--
Tamarack	1,584	--	--	--	--	704	473	163	--	244	--	--
Northern white-cedar	29,326	--	--	--	--	--	--	81	--	10,022	18,587	636
Oak-hickory	44,963	--	--	--	--	--	43	11,410	17,781	7,733	7,996	--
Elm-ash-maple	33,668	--	--	--	--	--	--	7,184	16,306	6,029	3,128	1,021
Maple-birch	154,006	--	--	--	--	--	--	11,540	43,669	15,661	83,136	--
Aspen	157,542	--	--	12,849	85,570	59,123	--	--	--	--	--	--
Paper birch	13,458	--	--	231	--	889	11,708	630	--	--	--	--
Exotic	2,158	--	1,439	719	--	--	--	--	--	--	--	--
All types	528,393	--	1,439	28,118	116,854	76,626	25,947	38,578	80,067	43,584	115,523	1,657
EASTERN UPPER PENINSULA												
Jack pine	5,364	--	--	--	4,452	912	--	--	--	--	--	--
Red pine	5,822	--	--	3,675	2,147	--	--	--	--	--	--	--
White pine	1,687	--	--	--	--	--	--	--	--	237	1,450	--
White spruce	978	--	--	--	--	--	137	672	169	--	--	--
Black spruce	4,874	--	--	--	2,751	2,123	--	--	--	--	--	--
Balsam fir	7,147	--	--	--	3,819	3,328	--	--	--	--	--	--
Tamarack	532	--	--	--	--	20	349	163	--	--	--	--
Northern white-cedar	14,546	--	--	--	--	--	--	--	--	5,839	8,707	--
Oak-hickory	340	--	--	--	--	--	43	--	154	143	--	--
Elm-ash-maple	4,773	--	--	--	--	--	--	--	1,432	3,134	207	--
Maple-birch	27,236	--	--	--	--	--	--	--	--	6,982	20,254	--
Aspen	31,286	--	--	--	24,932	6,354	--	--	--	--	--	--
Paper birch	3,920	--	--	--	--	853	3,067	--	--	--	--	--
Exotic	90	--	90	--	--	--	--	--	--	--	--	--
All types	108,595	--	90	3,675	38,101	13,590	3,596	835	1,755	16,335	30,618	--

(Table 22 continued on next page)

(Table 22 continued)

Forest type	All ages	1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
		Stand-age class (years)										
WESTERN UPPER PENINSULA												
Jack pine	2,654	--	--	--	--	2,654	--	--	--	--	--	--
Red pine	2,758	--	--	--	--	--	1,463	310	953	32	--	--
White pine	1,756	--	--	--	--	--	--	--	--	876	880	--
White spruce	1,938	--	--	--	--	289	698	605	--	--	346	--
Black spruce	4,060	--	--	--	--	158	2,802	1,100	--	--	--	--
Balsam fir	15,021	--	--	--	--	3,310	8,085	3,626	--	--	--	--
Tamarack	641	--	--	--	--	390	7	--	--	244	--	--
Northern white-cedar	4,370	--	--	--	--	--	--	--	--	--	3,734	636
Oak-hickory	332	--	--	--	--	--	--	--	--	--	332	--
Elm-ash-maple	3,942	--	--	--	--	--	--	--	--	--	2,921	1,021
Maple-birch	62,882	--	--	--	--	--	--	--	--	--	62,882	--
Aspen	35,399	--	--	--	14,024	21,375	--	--	--	--	--	--
Paper birch	6,063	--	--	--	--	36	5,397	630	--	--	--	--
All types	141,816	--	--	--	14,024	28,212	18,452	6,271	953	1,152	71,095	1,657
NORTHERN LOWER PENINSULA												
Jack pine	14,960	--	--	--	11,978	2,982	--	--	--	--	--	--
Red pine	15,358	--	--	10,471	4,887	--	--	--	--	--	--	--
White pine	2,750	--	--	--	--	--	--	--	--	2,750	--	--
White spruce	304	--	--	--	--	--	--	--	304	--	--	--
Black spruce	290	--	--	--	--	154	136	--	--	--	--	--
Balsam fir	1,086	--	--	--	--	--	--	201	885	--	--	--
Tamarack	411	--	--	--	--	294	117	--	--	--	--	--
Northern white-cedar	10,329	--	--	--	--	--	--	--	--	4,183	6,146	--
Oak-hickory	25,588	--	--	--	--	--	--	11,410	12,889	1,289	--	--
Elm-ash-maple	9,030	--	--	--	--	--	--	2,724	4,590	1,716	--	--
Maple-birch	44,369	--	--	--	--	--	--	11,540	32,217	612	--	--
Aspen	84,856	--	--	9,332	44,130	31,394	--	--	--	--	--	--
Paper birch	3,244	--	--	--	--	--	3,244	--	--	--	--	--
Exotic	1,435	--	1,128	307	--	--	--	--	--	--	--	--
All types	214,010	--	1,128	20,110	60,995	34,824	3,497	25,875	50,885	10,550	6,146	--
SOUTHERN LOWER PENINSULA												
Jack pine	464	--	--	--	163	--	301	--	--	--	--	--
Red pine	1,087	--	--	--	1,087	--	--	--	--	--	--	--
White pine	1,157	--	--	--	--	--	101	1,056	--	--	--	--
White spruce	173	--	--	173	--	--	--	--	--	--	--	--
Northern white-cedar	81	--	--	--	--	--	--	81	--	--	--	--
Oak-hickory	18,703	--	--	--	--	--	--	--	4,738	6,301	7,664	--
Elm-ash-maple	15,923	--	--	--	--	--	--	4,460	10,284	1,179	--	--
Maple-birch	19,519	--	--	--	--	--	--	--	11,452	8,067	--	--
Aspen	6,001	--	--	3,517	2,484	--	--	--	--	--	--	--
Paper birch	231	--	--	231	--	--	--	--	--	--	--	--
Exotic	633	--	221	412	--	--	--	--	--	--	--	--
All types	63,972	--	221	4,333	3,734	--	402	5,597	26,474	15,547	7,664	--

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[1] Tables may not add to totals due to rounding.

Table 23.--Commercial forest area qualifying for thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand acres)

Forest type	All ages	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS									
Red pine	171.2	--	50.1	113.4	7.7	--	--	--	--
White pine	1.7	--	--	1.7	--	--	--	--	--
White spruce	4.2	--	--	--	4.2	--	--	--	--
Oak-hickory	57.6	--	27.0	13.5	17.0	--	--	--	--
Maple-birch	2,402.2	--	120.2	118.1	273.9	759.6	744.0	386.5	--
All types	2,636.8	--	197.3	246.7	302.9	759.6	744.0	386.5	--
EASTERN UPPER PENINSULA									
Red pine	28.7	--	14.9	10.4	3.3	--	--	--	--
Oak-hickory	1.6	--	1.6	--	--	--	--	--	--
Maple-birch	458.0	--	30.1	26.5	57.0	151.4	117.5	75.6	--
All types	488.3	--	46.6	36.9	60.4	151.4	117.5	75.6	--
WESTERN UPPER PENINSULA									
Red pine	1.2	--	--	--	1.2	--	--	--	--
White pine	1.7	--	--	1.7	--	--	--	--	--
White spruce	1.6	--	--	--	1.6	--	--	--	--
Oak-hickory	1.6	--	--	1.6	--	--	--	--	--
Maple-birch	975.3	--	38.6	36.2	108.5	322.1	336.9	133.1	--
All types	981.4	--	38.6	39.5	111.3	322.1	336.9	133.1	--
NORTHERN LOWER PENINSULA									
Red pine	135.6	--	35.2	99.5	0.8	--	--	--	--
Oak-hickory	34.3	--	17.8	7.1	9.5	--	--	--	--
Maple-birch	746.1	--	21.7	26.0	69.1	242.5	256.8	129.9	--
All types	915.9	--	74.7	132.6	79.5	242.5	256.8	129.9	--
SOUTHERN LOWER PENINSULA									
Red pine	5.8	--	--	3.4	2.3	--	--	--	--
White spruce	2.6	--	--	--	2.6	--	--	--	--
Oak-hickory	20.0	--	7.6	4.9	7.5	--	--	--	--
Maple-birch	222.8	--	29.8	29.4	39.2	43.7	32.8	47.9	--
All types	251.2	--	37.4	37.7	51.7	43.7	32.8	47.9	--

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[1] Tables may not add to totals due to rounding.

Table 24.--Average annual yields from thinning by species group, tree class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

ALL UNITS

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	1,710	711	999	62	22	40
Red pine	14,409	9,386	5,023	223	--	223
White pine	2,300	835	1,465	111	31	80
White spruce	1,529	981	548	--	--	--
Black spruce	175	175	--	--	--	--
Balsam fir	5,312	4,319	993	25	--	25
Hemlock	1,467	347	1,120	75	19	56
Northern white-cedar	886	669	217	28	--	28
Other softwoods	313	164	149	58	--	58
Total	28,101	17,587	10,514	582	72	510
HARDWOODS						
White oak	520	227	293	12	--	12
Select red oak	2,604	512	2,092	103	70	33
Other red oak	507	91	416	92	--	92
Hickory	199	64	135	--	--	--
Basswood	10,896	2,714	8,182	576	196	380
Beech	617	507	110	86	--	86
Yellow birch	776	658	118	16	--	16
Hard maple	44,117	33,655	10,462	1,681	253	1428
Soft maple	24,260	15,325	8,935	1,465	144	1321
Elm	6,479	2,535	3,944	159	67	92
Ash	3,974	2,226	1,748	58	32	26
Cottonwood	69	--	69	--	--	--
Balsam poplar	154	81	73	--	--	--
Bigtooth aspen	2,911	1,247	1,664	116	16	100
Quaking aspen	3,373	1,317	2,056	226	28	198
Paper birch	2,159	1,315	844	51	29	22
Black cherry	4,127	2,499	1,628	198	15	183
Other hardwoods	703	476	227	--	--	--
Total	108,445	65,449	42,996	4,839	850	3,989
All species	136,546	83,036	53,510	5,421	922	4,499
EASTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	482	202	280	8	--	8
Red pine	1,075	944	131	22	--	22
White pine	342	13	329	49	15	34
White spruce	422	149	273	--	--	--
Black spruce	54	54	--	--	--	--
Balsam fir	1,512	1,161	351	--	--	--
Hemlock	283	31	252	25	--	25
Northern white-cedar	338	301	37	10	--	10
Total	4,508	2,855	1,653	114	15	99
HARDWOODS						
Select red oak	61	12	49	14	--	14
Basswood	1,177	233	944	154	63	91
Beech	368	322	46	36	--	36
Yellow birch	86	48	38	--	--	--
Hard maple	8,005	5,008	2,997	267	49	218
Soft maple	5,810	3,754	2,056	451	29	422
Elm	1,322	120	1,202	33	14	19
Ash	277	139	138	--	--	--
Balsam poplar	35	8	27	--	--	--
Bigtooth aspen	228	137	91	10	--	10
Quaking aspen	285	97	188	--	--	--
Paper birch	305	201	104	--	--	--
Black cherry	504	276	228	88	--	88
Total	18,463	10,355	8,108	1,053	155	898
All species	22,971	13,210	9,761	1,167	170	997

(Table 24 continued on next page)

(Table 24 continued)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
WESTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	137	64	73	9	9	--
Red pine	28	28	--	--	--	--
White pine	475	68	407	16	16	--
White spruce	830	663	167	--	--	--
Black spruce	101	101	--	--	--	--
Balsam fir	3,510	2,967	543	25	--	25
Hemlock	803	165	638	50	19	31
Northern white-cedar	245	161	84	--	--	--
Total	6,129	4,217	1,912	100	44	56
HARDWOODS						
Select red oak	581	101	480	--	--	--
Basswood	5,990	1,312	4,678	400	133	267
Yellow birch	560	480	80	16	--	16
Hard maple	17,935	14,080	3,855	1033	128	905
Soft maple	8,794	5,974	2,820	375	38	337
Elm	3,130	1,063	2,067	112	53	59
Ash	758	489	269	11	--	11
Balsam poplar	73	27	46	--	--	--
Bigtooth aspen	407	204	203	9	--	9
Quaking aspen	1,304	372	932	140	28	112
Paper birch	764	378	386	11	11	--
Black cherry	865	572	293	27	15	12
Other hardwoods	61	61				
Total	41,222	25,113	16,109	2,134	406	1,728
All species	47,351	29,330	18,021	2,234	450	1,784
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	908	320	588	45	13	32
Red pine	12,714	8,160	4,554	179	--	179
White pine	1,130	630	500	23	--	23
Black spruce	20	20	--	--	--	--
Balsam fir	290	191	99	--	--	--
Hemlock	358	128	230	--	--	--
Northern white-cedar	303	207	96	18	--	18
Other softwoods	141	56	85	48	--	48
Total	15,864	9,712	6,152	313	13	300
HARDWOODS						
White oak	196	46	150	12	--	12
Select red oak	1,523	145	1,378	42	23	19
Other red oak	507	91	416	92	--	92
Hickory	36	36	--	--	--	--
Basswood	3,577	1,017	2,560	22	--	22
Beech	249	185	64	50	--	50
Yellow birch	130	130	--	--	--	--
Hard maple	17,453	13,942	3,511	381	76	305
Soft maple	7,236	4,436	2,800	545	77	468
Elm	939	532	407	14	--	14
Ash	1,652	690	962	47	32	15
Cottonwood	25	--	25	--	--	--
Balsam poplar	46	46	--	--	--	--
Bigtooth aspen	2,021	868	1,153	97	16	81
Quaking aspen	1,784	848	936	86	--	86
Paper birch	1,022	668	354	40	18	22
Black cherry	1,021	407	614	83	--	83
Other hardwoods	24	--	24	--	--	--
Total	39,441	24,087	15,354	1,511	242	1,269
All species	55,305	33,799	21,506	1,824	255	1,569

(Table 24 continued on next page)

(Table 24 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2/]
SOFTWOODS						
Jack pine	183	125	58	--	--	--
Red pine	592	254	338	22	--	22
White pine	353	124	229	23	--	23
White spruce	277	169	108	--	--	--
Hemlock	23	23	--	--	--	--
Other softwoods	172	108	64	10	--	10
Total	1,600	803	797	55	--	55
HARDWOODS						
White oak	324	181	143	--	--	--
Select red oak	439	254	185	47	47	--
Hickory	163	28	135	--	--	--
Basswood	152	152	--	--	--	--
Hard maple	724	625	99	--	--	--
Soft maple	2,420	1,161	1,259	94	--	94
Elm	1,088	820	268	--	--	--
Ash	1,287	908	379	--	--	--
Cottonwood	44	--	44	--	--	--
Bigtooth aspen	255	38	217	--	--	--
Paper birch	68	68	--	--	--	--
Black cherry	1,737	1,244	493	--	--	--
Other hardwoods	618	415	203	--	--	--
Total	9,319	5,894	3,425	141	47	94
All species	10,919	6,697	4,222	196	47	149

[1/] Tables may not add to totals due to rounding.

[2/] Rough and rotten cull.

Table 25.--Average annual yields of growing-stock from thinning by species group, forest type, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

		Forest type[2]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
			ALL UNITS				
SOFTWOODS							
Jack pine	1,710	1,324	--	--	--	174	212
Red pine	14,409	13,167	--	--	--	308	934
White pine	2,300	406	56	--	--	--	1,838
White spruce	1,529	--	75	408	--	--	1,046
Black spruce	175	--	--	--	--	--	175
Balsam fir	5,312	--	--	--	--	--	5,312
Hemlock	1,467	--	--	--	--	--	1,467
Northern white-cedar	886	39	--	--	--	--	847
Other softwoods	313	185	--	--	--	--	128
Total	28,101	15,121	131	408	--	482	11,959
HARDWOODS							
White oak	520	90	--	--	--	116	314
Select red oak	2,604	462	--	--	--	281	1,861
Other red oak	507	384	--	--	--	123	--
Hickory	199	--	--	--	--	--	199
Basswood	10,896	--	--	--	--	--	10,896
Beech	617	--	--	--	--	--	617
Yellow birch	776	--	--	--	--	--	776
Hard maple	44,117	14	--	--	--	--	44,103
Soft maple	24,260	397	--	--	--	306	23,557
Elm	6,479	--	--	--	--	--	6,479
Ash	3,974	--	--	--	--	--	3,974
Cottonwood	69	--	--	--	--	--	69
Balsam poplar	154	--	--	--	--	--	154
Bigtooth aspen	2,911	286	--	--	--	371	2,254
Quaking aspen	3,373	173	--	--	--	99	3,101
Paper birch	2,159	28	--	--	--	--	2,131
Black cherry	4,127	96	--	--	--	62	3,969
Other hardwoods	703	--	--	--	--	--	703
Total	108,445	1,930	--	--	--	1,358	105,157
All species	136,546	17,051	131	408	--	1,840	117,116
			EASTERN UPPER PENINSULA				
SOFTWOODS							
Jack pine	482	482	--	--	--	--	--
Red pine	1,075	1,075	--	--	--	--	--
White pine	342	13	--	--	--	--	329
White spruce	422	--	--	--	--	--	422
Black spruce	54	--	--	--	--	--	54
Balsam fir	1,512	--	--	--	--	--	1,512
Hemlock	283	--	--	--	--	--	283
Northern white-cedar	338	--	--	--	--	--	338
Total	4,508	1,570	--	--	--	--	2,938
HARDWOODS							
Select red oak	61	--	--	--	--	--	61
Basswood	1,177	--	--	--	--	--	1,177
Beech	368	--	--	--	--	--	368
Yellow birch	86	--	--	--	--	--	86
Hard maple	8,005	--	--	--	--	--	8,005
Soft maple	5,810	115	--	--	--	172	5,523
Elm	1,322	--	--	--	--	--	1,322
Ash	277	--	--	--	--	--	277
Balsam poplar	35	--	--	--	--	--	35
Bigtooth aspen	228	12	--	--	--	--	216
Quaking aspen	285	17	--	--	--	--	268
Paper birch	305	--	--	--	--	--	305
Black cherry	504	--	--	--	--	--	504
Total	18,463	144	--	--	--	172	18,147
All species	22,971	1,714	--	--	--	172	21,085

(Table 25 continued on next page)

(Table 25 continued)

WESTERN UPPER PENINSULA

		Forest type[2/]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Jack pine	137	22	--	--	--	--	115
Red pine	28	--	--	--	--	--	28
White pine	475	--	56	--	--	--	419
White spruce	830	--	75	131	--	--	624
Black spruce	101	--	--	--	--	--	101
Balsam fir	3,510	--	--	--	--	--	3,510
Hemlock	803	--	--	--	--	--	803
Northern white-cedar	245	--	--	--	--	--	245
Total	6,129	22	131	131	--	--	5,845
HARDWOODS							
Select red oak	581	--	--	--	--	--	581
Basswood	5,990	--	--	--	--	--	5,990
Yellow birch	560	--	--	--	--	--	560
Hard maple	17,935	--	--	--	--	--	17,935
Soft maple	8,794	--	--	--	--	--	8,794
Elm	3,130	--	--	--	--	--	3,130
Ash	758	--	--	--	--	--	758
Balsam poplar	73	--	--	--	--	--	73
Bigtooth aspen	407	--	--	--	--	37	370
Quaking aspen	1,304	34	--	--	--	--	1,270
Paper birch	764	28	--	--	--	--	736
Black cherry	865	--	--	--	--	--	865
Other hardwoods	61	--	--	--	--	--	61
Total	41,222	62	--	--	--	37	41,123
All species	47,351	84	131	131	--	37	46,968
NORTHERN LOWER PENINSULA							
SOFTWOODS							
Jack pine	908	637	--	--	--	174	97
Red pine	12,714	11,759	--	--	--	308	647
White pine	1,130	393	--	--	--	--	737
Black spruce	20	--	--	--	--	--	20
Balsam fir	290	--	--	--	--	--	290
Hemlock	358	--	--	--	--	--	358
Northern white-cedar	303	39	--	--	--	--	264
Other softwoods	141	94	--	--	--	--	47
Total	15,864	12,922	--	--	--	482	2,460
HARDWOODS							
White oak	196	90	--	--	--	35	71
Select red oak	1,523	462	--	--	--	160	901
Other red oak	507	384	--	--	--	123	--
Hickory	36	--	--	--	--	--	36
Basswood	3,577	--	--	--	--	--	3,577
Beech	249	--	--	--	--	--	249
Yellow birch	130	--	--	--	--	--	130
Hard maple	17,453	14	--	--	--	--	17,439
Soft maple	7,236	282	--	--	--	116	6,838
Elm	939	--	--	--	--	--	939
Ash	1,652	--	--	--	--	--	1,652
Cottonwood	25	--	--	--	--	--	25
Balsam poplar	46	--	--	--	--	--	46
Bigtooth aspen	2,021	274	--	--	--	192	1,555
Quaking aspen	1,784	122	--	--	--	99	1,563
Paper birch	1,022	--	--	--	--	--	1,022
Black cherry	1,021	96	--	--	--	--	925
Other hardwoods	24	--	--	--	--	--	24
Total	39,441	1,724	--	--	--	725	36,992
All species	55,305	14,646	--	--	--	1,207	39,452

(Table 25 continued on next page)

(Table 25 continued)

SOUTHERN LOWER PENINSULA

Species group	Total	Forest type[2]					
		Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Jack pine	183	183	--	--	--	--	--
Red pine	592	333	--	--	--	--	259
White pine	353	--	--	--	--	--	353
White spruce	277	--	--	277	--	--	--
Hemlock	23	--	--	--	--	--	23
Other softwoods	172	91	--	--	--	--	81
Total	1,600	607	--	277	--	--	716
HARDWOODS							
White oak	324	--	--	--	--	81	243
Select red oak	439	--	--	--	--	121	318
Hickory	163	--	--	--	--	--	163
Basswood	152	--	--	--	--	--	152
Hard maple	724	--	--	--	--	--	724
Soft maple	2,420	--	--	--	--	18	2,402
Elm	1,088	--	--	--	--	--	1,088
Ash	1,287	--	--	--	--	--	1,287
Cottonwood	44	--	--	--	--	--	44
Bigtooth aspen	255	--	--	--	--	142	113
Paper birch	68	--	--	--	--	--	68
Black cherry	1,737	--	--	--	--	62	1,675
Other hardwoods	618	--	--	--	--	--	618
Total	9,319	--	--	--	--	424	8,895
All species	10,919	607	--	277	--	424	9,611

[1] Tables may not add to totals due to rounding.

[2] Thinning was a treatment option only in the forest types shown below.

Table 26.--Average annual yields of growing stock from thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

Forest type	All ages	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS									
Red pine	17,051	--	3,579	12,851	621	--	--	--	--
White pine	131	--	--	131	--	--	--	--	--
White spruce	408	--	--	--	408	--	--	--	--
Oak-hickory	1,840	--	1,027	325	488	--	--	--	--
Maple-birch	117,116	--	4,871	6,115	14,945	38,842	35,669	16,674	--
All types	136,546	--	9,477	19,422	16,462	38,842	35,669	16,674	--
EASTERN UPPER PENINSULA									
Red pine	1,714	--	278	1,192	244	--	--	--	--
Oak-hickory	172	--	172	--	--	--	--	--	--
Maple-birch	21,085	--	1,433	1,132	3,113	7,001	5,675	2,731	--
All types	22,971	--	1,883	2,324	3,357	7,001	5,675	2,731	--
WESTERN UPPER PENINSULA									
Red pine	84	--	--	--	84	--	--	--	--
White pine	131	--	--	131	--	--	--	--	--
White spruce	131	--	--	--	131	--	--	--	--
Oak-hickory	37	--	--	37	--	--	--	--	--
Maple-birch	46,968	--	1,601	1,820	5,665	15,837	16,207	5,838	--
All types	47,351	--	1,601	1,988	5,880	15,837	16,207	5,838	--
NORTHERN LOWER PENINSULA									
Red pine	14,646	--	3,301	11,269	76	--	--	--	--
Oak-hickory	1,207	--	654	207	346	--	--	--	--
Maple-birch	39,452	--	1,090	1,446	3,957	13,968	12,675	6,316	--
All types	55,305	--	5,045	12,922	4,379	13,968	12,675	6,316	--
SOUTHERN LOWER PENINSULA									
Red pine	607	--	--	390	217	--	--	--	--
White spruce	277	--	--	--	277	--	--	--	--
Oak-hickory	424	--	201	81	142	--	--	--	--
Maple-birch	9,611	--	747	1,717	2,210	2,036	1,112	1,789	--
All types	10,919	--	948	2,188	2,846	2,036	1,112	1,789	--

[1] Tables may not add to totals due to rounding.

Table 27.--Commercial forest area qualifying for timber stand improvement by forest type, stand-age class, and Forest Survey Unit, Michigan,1991-2000[1]

(In thousand acres)

		Stand-age class (years)								
Forest type	All ages	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS										
Jack pine	22.7	--	7.1	13.6	2.0	--	--	--	--	--
White pine	14.2	--	5.8	8.4	--	--	--	--	--	--
White spruce	7.5	--	--	7.5	--	--	--	--	--	--
Balsam fir	7.3	--	1.6	--	5.7	--	--	--	--	--
Northern white-cedar	45.0	--	--	--	--	45.0	--	--	--	--
Oak-hickory	24.2	--	--	19.3	2.3	2.7	--	--	--	--
Maple-birch	327.8	--	--	86.7	46.1	44.2	58.6	62.1	30.0	--
All types	448.6	--	14.5	135.5	56.1	91.9	58.6	62.1	30.0	--
EASTERN UPPER PENINSULA										
White pine	5.3	--	3.6	1.7	--	--	--	--	--	--
White spruce	3.2	--	--	3.2	--	--	--	--	--	--
Balsam fir	1.5	--	--	--	1.5	--	--	--	--	--
Northern white-cedar	34.5	--	--	--	--	34.5	--	--	--	--
Maple-birch	65.2	--	--	16.4	10.1	13.0	9.2	10.4	6.1	--
All types	109.6	--	3.6	21.2	11.7	47.5	9.2	10.4	6.1	--
WESTERN UPPER PENINSULA										
White spruce	1.6	--	--	1.6	--	--	--	--	--	--
Balsam fir	5.8	--	1.6	--	4.2	--	--	--	--	--
Northern white-cedar	1.4	--	--	--	--	1.4	--	--	--	--
Maple-birch	115.1	--	--	24.2	12.6	13.5	28.3	30.0	6.4	--
All types	123.9	--	1.6	25.9	16.8	14.9	28.3	30.0	6.4	--
NORTHERN LOWER PENINSULA										
Jack pine	22.7	--	7.1	13.6	2.0	--	--	--	--	--
White pine	8.9	--	2.2	6.7	--	--	--	--	--	--
White spruce	2.7	--	--	2.7	--	--	--	--	--	--
Northern white-cedar	9.1	--	--	--	--	9.1	--	--	--	--
Oak-hickory	12.1	--	--	7.2	2.3	2.7	--	--	--	--
Maple-birch	81.7	--	--	19.2	16.6	11.4	9.5	21.7	3.3	--
All types	137.2	--	9.2	49.4	20.9	23.2	9.5	21.7	3.3	--
SOUTHERN LOWER PENINSULA										
Oak-hickory	12.1	--	--	12.1	--	--	--	--	--	--
Maple-birch	65.8	--	--	26.9	6.8	6.3	11.6	--	14.2	--
All types	77.9	--	--	39.0	6.8	6.3	11.6	--	14.2	--

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[1] Tables may not add to totals due to rounding.

Table 28.--Average annual yields from timber stand improvement by species group, tree class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

Species group	Tree class					
	Growing stock			Cull		
	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
ALL UNITS						
SOFTWOODS						
Jack pine	21	--	21	--	--	--
White pine	54	--	54	--	--	--
White spruce	421	--	421	--	--	--
Balsam fir	610	505	105	--	--	--
Total	1,106	505	601	--	--	--
HARDWOODS						
White oak	42	--	42	--	--	--
Yellow birch	14	--	14	--	--	--
Hard maple	93	19	74	--	--	--
Soft maple	283	158	125	31	14	17
Elm	45	--	45	--	--	--
Balsam poplar	122	56	66	10	--	10
Quaking aspen	289	157	132	34	--	34
Paper birch	21	--	21	--	--	--
Total	909	390	519	75	14	61
All species	2,015	895	1,120	75	14	61
EASTERN UPPER PENINSULA						
SOFTWOODS						
White spruce	74	--	74	--	--	--
Balsam fir	513	467	46	--	--	--
Total	587	467	120	—	--	--
HARDWOODS						
Soft maple	178	158	20	31	14	17
Balsam poplar	93	56	37	10	--	10
Quaking aspen	164	82	82	--	--	--
Total	435	296	139	41	14	27
All species	1,022	763	259	41	14	27
WESTERN UPPER PENINSULA						
SOFTWOODS						
White spruce	129	--	129	--	--	--
Balsam fir	45	--	45	--	--	--
Total	174	--	174	--	--	--
HARDWOODS						
Yellow birch	14	--	14	--	--	--
Hard maple	93	19	74	--	--	--
Elm	45	--	45	--	--	--
Quaking aspen	34	--	34	13	--	13
Paper birch	21	--	21	--	--	--
Total	207	19	188	13	--	13
All species	381	19	362	13	--	13
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	21	--	21	--	--	--
White pine	54	--	54	--	--	--
White spruce	218	--	218	--	--	--
Balsam fir	52	38	14	--	--	--
Total	345	38	307	--	--	--
HARDWOODS						
White oak	42	--	42	--	--	--
Soft maple	105	--	105	--	--	--
Balsam poplar	29	--	29	--	--	--
Quaking aspen	91	75	16	21	--	21
Total	267	75	192	21	--	21
All species	612	113	499	21	--	21
SOUTHERN LOWER PENINSULA						
SOFTWOODS						
Total	--	--	--	--	--	--
HARDWOODS						
Total	--	--	--	--	--	--
All species	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 29.--Average annual yields of growing stock from timber stand improvement by species group, forest type, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

ALL UNITS

		Forest type[2]							
Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak hickory	Maple-birch
SOFTWOODS									
Jack pine	21	21	--	--	--	--	--	--	--
White pine	54	--	--	54	--	--	--	--	--
White spruce	421	--	--	34	302	85	--	--	--
Balsam fir	610	--	--	21	--	45	544	--	--
Total	1,106	21	--	109	302	130	544	--	--
HARDWOODS									
White oak	42	--	--	42	--	--	--	--	--
Yellow birch	14	--	--	--	14	--	--	--	--
Hard maple	93	--	--	--	93	--	--	--	--
Soft maple	283	--	--	283	--	--	--	--	--
Elm	45	--	--	--	45	--	--	--	--
Balsam poplar	122	--	--	--	--	54	68	--	--
Quaking aspen	289	--	--	59	--	34	196	--	--
Paper birch	21	--	--	--	--	21	--	--	--
Total	909	--	--	384	152	109	264	--	--
All species	2,015	21	--	493	454	239	808	--	--
EASTERN UPPER PENINSULA									
SOFTWOODS									
White spruce	74	--	--	34	40	--	--	--	--
Balsam fir	513	--	--	21	--	--	492	--	--
Total	587	--	--	55	40	--	492	--	--
HARDWOODS									
Soft maple	178	--	--	178	--	--	--	--	--
Balsam poplar	93	--	--	--	--	54	39	--	--
Quaking aspen	164	--	--	--	--	--	164	--	--
Total	435	--	--	178	--	54	203	--	--
All species	1,022	--	--	233	40	54	695	--	--
WESTERN UPPER PENINSULA									
SOFTWOODS									
White spruce	129	--	--	--	44	85	--	--	--
Balsam fir	45	--	--	--	--	45	--	--	--
Total	174	--	--	--	44	130	--	--	--
HARDWOODS									
Yellow birch	14	--	--	--	14	--	--	--	--
Hard maple	93	--	--	--	93	--	--	--	--
Elm	45	--	--	--	45	--	--	--	--
Quaking aspen	34	--	--	--	--	34	--	--	--
Paper birch	21	--	--	--	--	21	--	--	--
Total	207	--	--	--	152	55	--	--	--
All species	381	--	--	--	196	185	--	--	--

(Table 29 continued on next page)

(Table 29 continued)

NORTHERN LOWER PENINSULA

		Forest type[2]							
Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak hickory	Maple-birch
SOFTWOODS									
Jack pine	21	21	--	--	--	--	--	--	--
White pine	54	--	--	54	--	--	--	--	--
White spruce	218	--	--	--	218	--	--	--	--
Balsam fir	52	--	--	--	--	--	52	--	--
Total	345	21	--	54	218	--	52	--	--
HARDWOODS									
White oak	42	--	--	42	--	--	--	--	--
Soft maple	105	--	--	105	--	--	--	--	--
Balsam poplar	29	--	--	--	--	--	29	--	--
Quaking aspen	91	--	--	59	--	--	32	--	--
Total	267	--	--	206	--	--	61	--	--
All species	612	21	--	260	218	--	113	--	--

SOUTHERN LOWER PENINSULA

Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak hickory	Maple-birch
SOFTWOODS									
Total	--	--	--	--	--	--	--	--	--
HARDWOODS									
Total	--	--	--	--	--	--	--	--	--
All species	--	--	--	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

[2] Timber stand improvement was a treatment option only in the forest types shown below.

Table 30.--Average annual yields of growing stock from timber stand improvement by forest type, stand-age class, and Forest Survey Unit, Michigan, 1991-2000[1]

(In thousand cubic feet)

Forest type	All ages	Stand-age class (years)					
		1-10	11-20	21-30	31-40	41-50	51+
ALL UNITS							
Jack pine	21	--	--	--	21	--	--
White pine	493	--	258	235	--	--	--
White spruce	454	--	--	454	--	--	--
Balsam fir	239	--	185	--	54	--	--
Northern white-cedar	808	--	--	--	--	808	--
All types	2,015	--	443	689	75	808	--
EASTERN UPPER PENINSULA							
White pine	233	--	199	34	--	--	--
White spruce	40	--	--	40	--	--	--
Balsam fir	54	--	--	--	54	--	--
Northern white-cedar	695	--	--	--	--	695	--
All types	1,022	--	199	74	54	695	--
WESTERN UPPER PENINSULA							
White spruce	196	--	--	196	--	--	--
Balsam fir	185	--	185	--	--	--	--
All types	381	--	185	196	--	--	--
NORTHERN LOWER PENINSULA							
Jack pine	21	--	--	--	21	--	--
White pine	260	--	59	201	--	--	--
White spruce	218	--	--	218	--	--	--
Northern white-cedar	113	--	--	--	--	113	--
All types	612	--	59	419	21	113	--
SOUTHERN LOWER PENINSULA							
All types	--	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

Table 31.--Commercial forest area qualifying for treatment and average annual yields of growing stock from each treatment by treatment category and Forest Survey Unit, Michigan, 2001-2010[1]

Treatment	All units	Forest Survey Unit			
		Eastern Upper Peninsula	Western Upper Peninsula	Northern Lower Peninsula	Southern Lower Peninsula
COMMERCIAL FOREST AREA					
		In thousand acres			
Harvest	2,517.6	547.7	636.2	1,043.4	290.3
Thinning	2,600.7	449.9	930.1	872.9	347.8
Timber stand improvement	316.6	100.3	90.9	76.8	48.6
No treatment	11,784.9	2,611.0	2,773.2	4,706.0	1,694.7
Total	17,219.8	3,708.9	4,430.4	6,699.1	2,381.4
AVERAGE ANNUAL YIELDS OF GROWING STOCK					
		In thousand cubic feet			
Harvest	576,389	126,521	162,588	218,215	69,065
Thinning	160,570	26,704	53,788	58,763	21,315
Timber stand improvement	3,307	1,344	326	1,637	--
Total	740,266	154,569	216,702	278,615	90,380

[1] Tables may not add to totals due to rounding.

Table 32.--Commercial forest area qualifying for harvest by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand acres)

ALL UNITS

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	148.5	--	--	--	80.7	58.5	9.3	--	--	--	--	--
Red pine	111.1	--	--	58.9	47.0	2.4	1.7	1.1	--	--	--	--
White pine	25.9	--	--	--	--	--	--	2.3	4.0	19.7	--	--
White spruce	12.6	--	--	--	1.0	1.5	7.4	1.2	--	1.5	--	--
Black spruce	65.4	--	--	--	33.0	7.7	24.7	--	--	--	--	--
Balsam fir	108.7	--	--	--	--	61.7	41.3	4.9	0.8	--	--	--
Tamarack	13.4	--	--	--	1.2	3.3	8.9	--	--	--	--	--
Northern white-cedar	148.1	--	--	--	--	--	--	--	5.6	124.1	18.3	--
Oak-hickory	224.0	--	--	--	--	--	1.3	123.6	35.8	61.6	1.7	--
Elm-ash-maple	147.0	--	--	--	--	--	21.2	55.6	46.5	22.5	1.2	--
Maple-birch	680.9	--	--	--	--	--	--	161.5	108.3	367.7	43.4	--
Aspen	750.7	--	279.5	117.4	264.9	89.0	--	--	--	--	--	--
Paper birch	67.8	--	0.1	--	1.0	1.9	62.9	1.9	--	--	--	--
Exotic	13.5	--	--	13.5	--	--	--	--	--	--	--	--
All types	2,517.6	--	279.6	189.8	428.8	226.0	178.7	352.0	200.9	597.1	64.7	--

EASTERN UPPER PENINSULA

Forest type	All ages	1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	36.3	--	--	--	3.0	33.3	--	--	--	--	--	--
Red pine	25.5	--	--	5.3	20.2	--	--	--	--	--	--	--
White pine	8.5	--	--	--	--	--	--	--	4.0	4.5	--	--
White spruce	3.6	--	--	--	--	--	2.3	1.2	--	--	--	--
Black spruce	34.8	--	--	--	33.0	1.8	--	--	--	--	--	--
Balsam fir	36.1	--	--	--	--	36.1	--	--	--	--	--	--
Tamarack	5.3	--	--	--	--	--	5.3	--	--	--	--	--
Northern white-cedar	77.4	--	--	--	--	--	--	--	4.7	72.7	--	--
Oak-hickory	2.5	--	--	--	--	--	1.3	1.1	--	--	--	--
Elm-ash-maple	20.7	--	--	--	--	--	--	3.0	14.0	3.8	--	--
Maple-birch	125.5	--	--	--	--	--	--	--	--	125.5	--	--
Aspen	149.5	--	14.7	24.5	107.5	2.9	--	--	--	--	--	--
Paper birch	21.5	--	--	--	--	1.9	19.6	--	--	--	--	--
Exotic	0.4	--	--	0.4	--	--	--	--	--	--	--	--
All types	547.7	--	14.7	30.2	163.8	76.0	28.6	5.3	22.6	206.5	--	--

(Table 32 continued on next page)

(Table 32 continued)

Forest type	All ages	Stand-age class (years) 1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
WESTERN UPPER PENINSULA												
Jack pine	14.3	--	--	--	--	5.0	9.3	--	--	--	--	--
Red pine	9.5	--	--	--	6.6	--	1.7	1.1	--	--	--	--
White pine	5.0	--	--	--	--	--	--	--	--	5.0	--	--
White spruce	6.5	--	--	--	--	1.5	5.1	--	--	--	--	--
Black spruce	27.5	--	--	--	--	3.6	23.9	--	--	--	--	--
Balsam fir	66.9	--	--	--	--	25.6	41.3	--	--	--	--	--
Tamarack	5.0	--	--	--	0.3	3.3	1.5	--	--	--	--	--
Northern white-cedar	25.0	--	--	--	--	--	--	--	--	6.7	18.3	--
Oak-hickory	1.9	--	--	--	--	--	--	--	--	0.2	1.7	--
Elm-ash-maple	19.9	--	--	--	--	--	--	--	--	18.7	1.2	--
Maple-birch	270.8	--	--	--	--	--	--	--	--	227.3	43.4	--
Aspen	155.9	--	--	--	69.8	86.1	--	--	--	--	--	--
Paper birch	27.9	--	--	--	--	--	27.9	--	--	--	--	--
All types	636.2	--	--	--	76.7	125.1	110.6	1.1	--	258.0	64.7	--
NORTHERN LOWER PENINSULA												
Jack pine	95.5	--	--	--	77.7	17.8	--	--	--	--	--	--
Red pine	71.7	--	--	53.6	18.1	--	--	--	--	--	--	--
White pine	10.2	--	--	--	--	--	--	--	--	10.2	--	--
White spruce	1.5	--	--	--	--	--	--	--	--	1.5	--	--
Black spruce	3.1	--	--	--	--	2.3	0.8	--	--	--	--	--
Balsam fir	5.6	--	--	--	--	--	--	4.9	0.8	--	--	--
Tamarack	3.1	--	--	--	1.0	--	2.1	--	--	--	--	--
Northern white-cedar	44.6	--	--	--	--	--	--	--	--	44.6	--	--
Oak-hickory	134.2	--	--	--	--	--	--	122.5	11.7	--	--	--
Elm-ash-maple	41.1	--	--	--	--	--	--	21.4	19.7	--	--	--
Maple-birch	193.2	--	--	--	--	--	--	139.1	54.1	--	--	--
Aspen	414.1	--	257.1	78.9	78.1	--	--	--	--	--	--	--
Paper birch	17.3	--	--	--	--	--	15.4	1.9	--	--	--	--
Exotic	8.2	--	--	8.2	--	--	--	--	--	--	--	--
All types	1,043.4	--	257.1	140.8	174.8	20.1	18.4	289.7	86.3	56.4	--	--
SOUTHERN LOWER PENINSULA												
Jack pine	2.4	--	--	--	--	2.4	--	--	--	--	--	--
Red pine	4.4	--	--	--	2.0	2.4	--	--	--	--	--	--
White pine	2.3	--	--	--	--	--	--	2.3	--	--	--	--
White spruce	1.0	--	--	--	1.0	--	--	--	--	--	--	--
Northern white-cedar	1.0	--	--	--	--	--	--	--	1.0	--	--	--
Oak-hickory	85.4	--	--	--	--	--	--	--	24.0	61.4	--	--
Elm-ash-maple	65.3	--	--	--	--	--	21.2	31.2	12.8	--	--	--
Maple-birch	91.4	--	--	--	--	--	--	22.4	54.1	14.9	--	--
Aspen	31.2	--	7.7	13.9	9.6	--	--	--	--	--	--	--
Paper birch	1.0	--	0.1	--	1.0	--	--	--	--	--	--	--
Exotic	4.9	--	--	4.9	--	--	--	--	--	--	--	--
All types	290.3	--	7.8	18.9	13.5	4.8	21.2	55.9	92.0	76.3	--	--

[1] Tables may not add to totals due to rounding.

Table 33.--Average annual yields from harvest by species group, tree class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

ALL UNITS

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	23,160	4,885	18,275	804	86	718
Red pine	39,921	2,609	37,312	68	17	51
White pine	19,795	1,228	18,567	304	126	178
White spruce	27,078	1,883	25,195	227	36	191
Black spruce	10,817	8,625	2,192	36	--	36
Balsam fir	28,966	12,953	16,013	579	21	558
Hemlock	11,519	860	10,659	581	210	371
Tamarack	907	522	385	33	--	33
Northern white-cedar	37,270	13,821	23,449	2,943	479	2,464
Other softwoods	2,546	1,571	975	301	29	272
Total	201,979	48,957	153,022	5,876	1,004	4,872
HARDWOODS						
White oak	12,910	1,917	10,993	237	24	213
Select red oak	31,890	2,971	28,919	1,183	354	829
Other red oak	7,080	596	6,484	328	23	305
Hickory	2,376	265	2,111	40	40	--
Basswood	18,245	748	17,497	940	113	827
Beech	7,385	1,255	6,130	939	98	841
Yellow birch	8,025	1,114	6,911	1,236	293	943
Hard maple	66,208	14,494	51,714	4,509	1,083	3,426
Soft maple	67,891	14,631	53,260	4,733	622	4,111
Elm	8,384	1,412	6,972	370	36	334
Ash	14,547	4,715	9,832	420	66	354
Cottonwood	949	--	949	--	--	--
Balsam poplar	6,039	757	5,282	186	30	156
Bigtooth aspen	26,844	10,021	16,823	994	73	921
Quaking aspen	58,942	12,537	46,405	4,049	283	3,766
Paper birch	23,871	6,850	17,021	1,237	50	1,187
Black cherry	9,826	1,784	8,042	785	30	755
Other hardwoods	2,998	758	2,240	224	16	208
Total	374,410	76,825	297,585	22,410	3,234	19,176
All species	576,389	125,782	450,607	28,286	4,238	24,048
EASTERN UPPER PENINSULA						
SOFTWOODS						
Jack pine	6,107	1,776	4,331	242	2	240
Red pine	7,385	367	7,018	17	17	--
White pine	4,286	306	3,980	143	76	67
White spruce	13,141	514	12,627	191	--	191
Black spruce	5,855	5,138	717	6	--	6
Balsam fir	9,248	4,821	4,427	216	9	207
Hemlock	2,290	226	2,064	58	20	38
Tamarack	328	160	168	11	--	11
Northern white-cedar	15,716	6,369	9,347	1,172	219	953
Other softwoods	55	16	39	--	--	--
Total	64,411	19,693	44,718	2,056	343	1,713
HARDWOODS						
White oak	14	--	14	--	--	--
Select red oak	694	65	629	70	13	57
Basswood	1,301	111	1,190	53	--	53
Beech	3,364	618	2,746	540	51	489
Yellow birch	1,211	133	1,078	96	31	65
Hard maple	13,565	2,737	10,828	896	303	593
Soft maple	12,265	2,464	9,801	1,366	122	1,244
Elm	1,574	78	1,496	117	--	117
Ash	976	490	486	48	11	37
Balsam poplar	2,918	272	2,646	36	--	36
Bigtooth aspen	2,317	99	2,218	38	--	38
Quaking aspen	13,583	2,799	10,784	1,044	30	1,014
Paper birch	7,860	2,708	5,152	219	8	211
Black cherry	468	--	468	145	--	145
Total	62,110	12,574	49,536	4,668	569	4,099
All species	126,521	32,267	94,254	6,724	912	5,812

(Table 33 continued on next page)

(Table 33 continued)

WESTERN UPPER PENINSULA

Species group	Tree class					
	Growing stock			Cull		
	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2/]
SOFTWOODS						
Jack pine	3,212	293	2,919	83	49	34
Red pine	4,400	322	4,078	9	--	9
White pine	4,516	86	4,430	37	27	10
White spruce	11,210	869	10,341	36	36	--
Black spruce	4,496	3,232	1,264	30	--	30
Balsam fir	16,610	7,127	9,483	303	12	291
Hemlock	7,829	447	7,382	494	190	304
Tamarack	363	211	152	4	--	4
Northern white-cedar	7,655	1,482	6,173	1,030	208	822
Other softwoods	19	19	--	--	--	--
Total	60,310	14,088	46,222	2,026	522	1,504
HARDWOODS						
Select red oak	2,131	252	1,879	73	47	26
Basswood	4,971	185	4,786	595	80	515
Yellow birch	5,768	807	4,961	930	232	698
Hard maple	32,695	7,269	25,426	3,156	711	2,445
Soft maple	17,324	5,254	12,070	1,895	296	1,599
Elm	3,765	389	3,376	156	36	120
Ash	2,279	653	1,626	103	11	92
Balsam poplar	600	81	519	23	15	8
Bigtooth aspen	2,266	273	1,993	292	44	248
Quaking aspen	19,634	2,222	17,412	1,490	193	1,297
Paper birch	9,231	2,585	6,646	829	42	787
Black cherry	1,594	340	1,254	140	30	110
Other hardwoods	20	--	20	67	16	51
Total	102,278	20,310	81,968	9,749	1,753	7,996
All species	162,588	34,398	128,190	11,775	2,275	9,500

NORTHERN LOWER PENINSULA

Species group	Growing stock Total	Pole-timber	Saw-timber	Cull Total	Shortlog	Other[2/]
SOFTWOODS						
Jack pine	12,969	2,658	10,311	479	35	444
Red pine	26,453	1,736	24,717	--	--	--
White pine	8,225	739	7,486	57	--	57
White spruce	2,522	346	2,176	--	--	--
Black spruce	466	255	211	--	--	--
Balsam fir	3,108	1,005	2,103	60	--	60
Hemlock	1,302	169	1,133	29	--	29
Tamarack	188	123	65	18	--	18
Northern white-cedar	13,817	5,959	7,858	741	52	689
Other softwoods	1,564	1,117	447	178	--	178
Total	70,614	14,107	56,507	1,562	87	1,475
HARDWOODS						
White oak	6,413	1,676	4,737	205	24	181
Select red oak	21,718	2,248	19,470	825	228	597
Other red oak	4,230	365	3,865	214	23	191
Hickory	112	30	82	--	--	--
Basswood	8,718	224	8,494	184	23	161
Beech	2,637	370	2,267	173	47	126
Yellow birch	738	174	564	97	--	97
Hard maple	15,611	3,880	11,731	428	69	359
Soft maple	24,107	4,614	19,493	787	141	646
Elm	730	237	493	58	--	58
Ash	5,655	1,657	3,998	182	9	173
Cottonwood	317	--	317	--	--	--
Balsam poplar	2,090	404	1,686	127	15	112
Bigtooth aspen	21,296	9,500	11,796	664	29	635
Quaking aspen	23,332	7,301	16,031	1,366	60	1,306
Paper birch	6015	1433	4582	189	--	189
Black cherry	3,571	1,082	2,489	296	--	296
Other hardwoods	311	14	297	--	--	--
Total	147,601	35,209	112,392	5,795	668	5,127
All species	218,215	49,316	168,899	7,357	755	6,602

(Table 33 continued on next page)

(Table 33 continued)

SOUTHERN LOWER PENINSULA

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Jack pine	872	158	714	--	--	--
Red pine	1,683	184	1,499	42	--	42
White pine	2,768	97	2,671	67	23	44
White spruce	205	154	51	--	--	--
Hemlock	98	18	80	--	--	--
Tamarack	28	28	--	--	--	--
Northern white-cedar	82	11	71	--	--	--
Other softwoods	908	419	489	123	29	94
Total	6,644	1,069	5,575	232	52	180
HARDWOODS						
White oak	6,483	241	6,242	32	--	32
Select red oak	7,347	406	6,941	215	66	149
Other red oak	2,850	231	2,619	114	--	114
Hickory	2,264	235	2,029	40	40	--
Basswood	3,255	228	3,027	108	10	98
Beech	1,384	267	1,117	226	--	226
Yellow birch	308	--	308	113	30	83
Hard maple	4,337	608	3,729	29	--	29
Soft maple	14,195	2,299	11,896	685	63	622
Elm	2,315	708	1,607	39	--	39
Ash	5,637	1,915	3,722	87	35	52
Cottonwood	632	--	632	--	--	--
Balsam poplar	431	--	431	--	--	--
Bigtooth aspen	965	149	816	--	--	--
Quaking aspen	2,393	215	2,178	149	--	149
Paper birch	765	124	641	--	--	--
Black cherry	4,193	362	3,831	204	--	204
Other hardwoods	2,667	744	1,923	157	--	157
Total	62,421	8,732	53,689	2,198	244	1,954
All species	69,065	9,801	59,264	2,430	296	2,134

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[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 34.--Average annual yields of growing stock from harvest by species group, forest type, and Forest Survey Unit, Michigan, 2001-2010[1/]

(In thousand cubic feet)

ALL UNITS

		Forest type												
Species group	All types	Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	23,160	18,258	636	47	--	715	--	--	--	1,245	--	--	2,110	149	--
Red pine	39,921	4,550	28,267	380	23	271	--	--	15	1,027	363	273	4,668	34	50
White pine	19,795	820	538	5,825	245	988	709	--	1,229	1,297	59	2,743	5,162	180	--
White spruce	27,078	95	657	221	2,594	185	11,017	--	771	41	399	2,871	7,930	259	38
Black spruce	10,817	608	105	213	74	6,876	1,101	174	1,031	8	128	151	311	37	--
Balsam fir	28,966	106	105	351	237	470	8,621	93	1,904	--	872	3,905	10,877	1,425	--
Hemlock	11,519	--	--	80	--	22	160	--	151	--	309	10,493	239	65	--
Tamarack	907	--	22	18	--	169	55	395	83	--	34	25	65	41	--
Northern white-cedar	37,270	29	44	46	425	168	1,699	283	23,983	--	2,243	4,101	3,303	946	--
Other softwoods	2,546	--	--	--	73	19	1	--	--	--	--	113	269	--	2,071
Total	201,979	24,466	30,374	7,181	3,671	9,883	23,363	945	29,167	3,618	4,407	24,675	34,934	3,136	2,159
HARDWOODS															
White oak	12,910	58	18	25	--	--	--	--	--	11,210	104	968	489	38	--
Select red oak	31,890	709	--	162	--	--	103	--	--	18,611	345	5,886	5,590	484	--
Other red oak	7,080	698	--	--	--	--	--	--	--	5,502	45	565	270	--	--
Hickory	2,376	30	30	--	--	--	--	--	--	1,772	--	517	--	27	--
Basswood	18,245	32	70	--	--	--	29	--	24	679	1,057	15,012	986	356	--
Beech	7,385	--	--	15	--	--	--	--	--	193	87	6,743	162	185	--
Yellow birch	8,025	--	--	--	3	--	99	--	204	49	317	7,068	271	14	--
Hard maple	66,208	21	40	346	13	115	295	--	111	539	466	59,281	4,401	580	--
Soft maple	67,891	251	155	189	36	91	902	--	1,168	5,096	13,684	25,880	18,390	2,049	--
Elm	8,384	--	--	8	--	31	269	--	46	110	2,417	3,525	1,977	1	--
Ash	14,547	--	--	--	--	--	39	--	524	735	6,015	4,696	2,321	217	--
Cottonwood	949	--	--	--	--	--	--	--	--	52	364	321	212	--	--
Balsam poplar	6,039	--	--	--	49	27	298	6	156	--	152	425	4,587	189	150
Bigtooth aspen	26,844	25	85	7	--	--	--	--	26	2,235	14	1,967	22,109	376	--
Quaking aspen	58,942	232	132	399	245	1,280	1,776	100	322	735	712	3,464	48,747	798	--
Paper birch	23,871	--	73	167	79	361	1,256	5	1,615	314	696	2,399	7,854	9,052	--
Black cherry	9,826	--	--	34	49	--	469	--	--	1,631	403	3,387	3,774	--	79
Other hardwoods	2,998	33	--	--	--	--	--	--	28	411	842	1,409	275	--	--
Total	374,410	2,089	603	1,352	474	1,905	5,535	111	4,224	49,874	27,720	143,513	122,415	14,366	229
All species	576,389	26,555	30,977	8,533	4,145	11,788	28,898	1,056	33,391	53,492	32,127	168,188	157,349	17,502	2,388

(Table 34 continued on next page)

(Table 34 continued)

NORTHERN LOWER PENINSULA

Species group	All types	Forest type Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	12,969	10,649	41	47	--	--	--	--	--	917	--	--	1,315	--	--
Red pine	26,453	3,064	18,595	252	--	--	--	--	--	902	--	273	3,367	--	--
White pine	8,225	56	--	2,372	--	233	--	--	284	534	--	776	3,914	56	--
White spruce	2,522	--	163	--	143	43	238	--	155	--	--	--	1,744	36	--
Black spruce	466	93	--	60	--	119	--	3	191	--	--	--	--	--	--
Balsam fir	3,108	--	--	99	11	10	414	7	394	--	19	114	1,817	223	--
Hemlock	1,302	--	--	--	--	--	--	--	92	--	58	1,062	59	31	--
Tamarack	188	--	--	--	--	--	1	104	14	--	--	25	18	26	--
Northern white-cedar	13,817	--	--	--	82	24	150	103	8,874	--	1,494	1,022	1,847	221	--
Other softwoods	1,564	--	--	--	--	--	--	--	--	--	--	--	269	--	1,295
Total	70,614	13,862	18,799	2,830	236	429	803	217	10,004	2,353	1,571	3,272	14,350	593	1,295
HARDWOODS															
White oak	6,413	58	18	--	--	--	--	--	--	5,797	--	137	365	38	--
Select red oak	21,718	672	--	44	--	--	--	--	--	13,088	--	2,304	5,208	402	--
Other red oak	4,230	698	--	--	--	--	--	--	--	3,225	--	37	270	--	--
Hickory	112	--	30	--	--	--	--	--	--	--	--	55	--	27	--
Basswood	8,718	32	70	--	--	--	--	--	24	220	401	7,352	401	218	--
Beech	2,637	--	--	--	--	--	--	--	--	49	--	2,274	129	185	--
Yellow birch	738	--	--	--	--	--	--	--	39	--	124	575	--	--	--
Hard maple	15,611	--	40	--	--	--	--	--	--	144	70	13,555	1,742	60	--
Soft maple	24,107	92	3	55	--	36	--	--	514	2,322	4,263	6,153	10,148	521	--
Elm	730	--	--	--	--	3	--	--	--	--	186	158	383	--	--
Ash	5,655	--	--	--	--	--	--	--	287	152	1,456	2,594	983	183	--
Cottonwood	317	--	--	--	--	--	--	--	--	--	--	105	212	--	--
Balsam poplar	2,090	--	--	--	43	20	--	1	99	--	120	55	1,556	46	150
Bigtooth aspen	21,296	25	85	7	--	--	--	--	18	1,826	--	1,260	17,901	174	--
Quaking aspen	23,332	138	--	32	17	116	90	--	181	531	330	1,217	20,389	291	--
Paper birch	6,015	--	--	93	--	31	196	5	662	176	282	763	1,837	1,970	--
Black cherry	3,571	--	--	34	--	--	132	--	--	354	--	781	2,270	--	--
Other hardwoods	311	--	--	--	--	--	--	--	14	21	47	61	168	--	--
Total	147,601	1,715	246	265	60	206	418	6	1,838	27,905	7,279	39,436	63,962	4,115	150
All species	218,215	15,577	19,045	3,095	296	635	1,221	223	11,842	30,258	8,850	42,708	78,312	4,708	1,445

(Table 34 continued on next page)

(Table 34 continued)

WESTERN UPPER PENINSULA

Species group	All types	Forest type Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	3,212	2,146	103	--	--	123	--	--	--	--	--	--	691	149	--
Red pine	4,400	298	2,576	44	--	271	--	--	--	--	--	--	1,177	34	--
White pine	4,516	338	239	1,057	80	108	557	--	162	36	39	999	799	102	--
White spruce	11,210	36	--	133	1,807	142	3,562	--	153	--	198	1,942	3,119	118	--
Black spruce	4,496	81	4	--	74	2,926	670	124	161	8	12	151	267	18	--
Balsam fir	16,610	106	41	240	170	460	6,926	62	311	--	412	2,658	4,470	754	--
Hemlock	7,829	--	--	--	--	22	160	--	6	--	154	7,370	105	12	--
Tamarack	363	--	--	--	--	136	54	135	9	--	--	--	14	15	--
Northern white-cedar	7,655	--	--	31	--	144	811	--	3,448	--	373	2,561	201	86	--
Other softwoods	19	--	--	--	--	19	--	--	--	--	--	--	--	--	--
Total	60,310	3,005	2,963	1,505	2,131	4,351	12,740	321	4,250	44	1,188	15,681	10,843	1,288	--
HARDWOODS															
Select red oak	2,131	--	--	--	--	--	103	--	--	235	14	1,564	198	17	--
Basswood	4,971	--	--	--	--	--	29	--	--	--	66	4,533	343	--	--
Yellow birch	5,768	--	--	--	--	--	99	--	143	--	171	5,124	217	14	--
Hard maple	32,695	--	--	55	--	--	295	--	94	180	300	29,396	2,259	116	--
Soft maple	17,324	--	22	17	36	55	762	--	273	1	1,086	9,929	4,594	549	--
Elm	3,765	--	--	8	--	28	254	--	12	--	600	2,560	303	--	--
Ash	2,279	--	--	--	--	--	28	--	76	--	939	815	396	25	--
Balsam poplar	600	--	--	--	6	7	141	--	--	--	7	22	417	--	--
Bigtooth aspen	2,266	--	--	--	--	--	--	--	--	--	--	84	2,112	70	--
Quaking aspen	19,634	31	66	255	205	83	1,596	65	--	1	82	1,419	15,701	130	--
Paper birch	9,231	--	73	33	63	319	834	--	131	12	123	968	2,292	4,383	--
Black cherry	1,594	--	--	--	--	--	337	--	--	--	15	790	452	--	--
Other hardwoods	20	--	--	--	--	--	--	--	--	--	20	--	--	--	--
Total	102,278	31	161	368	310	492	4,478	65	729	429	3,423	57,204	29,284	5,304	--
All species	162,588	3,036	3,124	1,873	2,441	4,843	17,218	386	4,979	473	4,611	72,885	40,127	6,592	--

(Table 34 continued on next page)

(Table 34 continued)

EASTERN UPPER PENINSULA

Species group	All types	Forest type: Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	6,107	4,972	439	--	--	592	--	--	--	--	--	--	104	--	--
Red pine	7,385	1,188	6,039	84	23	--	--	--	15	16	--	--	--	--	20
White pine	4,286	426	49	1,375	165	647	152	--	783	--	20	543	104	22	--
White spruce	13,141	59	494	88	534	--	7,217	--	463	41	201	834	3,067	105	38
Black spruce	5,855	434	101	153	--	3,831	431	47	679	--	116	--	44	19	--
Balsam fir	9,248	--	64	12	56	--	1,281	24	1,199	--	441	1,133	4,590	448	--
Hemlock	2,290	--	--	80	--	--	--	--	53	--	97	1,963	75	22	--
Tamarack	328	--	22	18	--	33	--	156	60	--	6	--	33	--	--
Northern white-cedar	15,716	29	44	15	343	--	738	180	11,582	--	376	518	1,255	636	--
Other softwoods	55	--	--	--	--	--	1	--	--	--	--	--	--	--	54
Total	64,411	7,108	7,252	1,825	1,121	5,103	9,820	407	14,834	57	1,257	4,991	9,272	1,252	112
HARDWOODS															
White oak	14	--	--	--	--	--	--	--	--	14	--	--	--	--	--
Select red oak	694	37	--	--	--	--	--	--	--	316	--	163	113	65	--
Basswood	1,301	--	--	--	--	--	--	--	--	--	--	1,059	242	--	--
Beech	3,364	--	--	15	--	--	--	--	--	--	--	3,349	--	--	--
Yellow birch	1,211	--	--	--	3	--	--	--	22	--	22	1,110	54	--	--
Hard maple	13,565	21	--	291	13	115	--	--	17	26	96	12,182	400	404	--
Soft maple	12,265	159	130	117	--	--	140	--	381	107	1,125	6,146	3,029	931	--
Elm	1,574	--	--	--	--	--	15	--	34	--	301	507	717	--	--
Ash	976	--	--	--	--	--	11	--	161	--	415	94	287	8	--
Balsam poplar	2,918	--	--	--	--	--	157	5	57	--	25	175	2,356	143	--
Bigtooth aspen	2,317	--	--	--	--	--	--	--	8	--	14	328	1,835	132	--
Quaking aspen	13,583	63	66	112	23	1,081	90	35	132	12	51	551	11,002	365	--
Paper birch	7,860	--	--	41	16	11	226	--	822	--	291	668	3,161	2,624	--
Black cherry	468	--	--	--	--	--	--	--	--	--	--	404	64	--	--
Total	62,110	280	196	576	55	1,207	639	40	1,634	475	2,340	26,736	23,260	4,672	--
All species	126,521	7,388	7,448	2,401	1,176	6,310	10,459	447	16,468	532	3,597	31,727	32,532	5,924	112

(Table 34 continued on next page)

(Table 34 continued)

SOUTHERN LOWER PENINSULA

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	White spruce	Black spruce	Balsam fir	Tamarack	Northern white-cedar	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
SOFTWOODS															
Jack pine	872	491	53	--	--	--	--	--	--	328	--	--	--	--	--
Red pine	1,683	--	1,057	--	--	--	--	--	--	109	363	--	124	--	30
White pine	2,768	--	250	1,021	--	--	--	--	--	727	--	425	345	--	--
White spruce	205	--	--	--	110	--	--	--	--	--	--	95	--	--	--
Hemlock	98	--	--	--	--	--	--	--	--	--	--	98	--	--	--
Tamarack	28	--	--	--	--	--	--	--	--	--	28	--	--	--	--
Northern white-cedar	32	--	--	--	--	--	--	--	79	--	--	--	--	3	--
Other softwoods	908	--	--	--	73	--	--	--	--	--	--	113	--	--	722
Total	6,644	491	1,360	1,021	183	--	--	--	79	1,164	391	731	469	3	752
HARDWOODS															
White oak	6,483	--	--	25	--	--	--	--	--	5,399	104	831	124	--	--
Select red oak	7,347	--	--	118	--	--	--	--	--	4,972	331	1,855	71	--	--
Other red oak	2,850	--	--	--	--	--	--	--	--	2,277	45	528	--	--	--
Hickory	2,264	30	--	--	--	--	--	--	--	1,772	--	462	--	--	--
Basswood	3,255	--	--	--	--	--	--	--	--	459	590	2,068	--	138	--
Beech	1,384	--	--	--	--	--	--	--	--	144	87	1,120	33	--	--
Yellow birch	308	--	--	--	--	--	--	--	--	49	--	259	--	--	--
Hard maple	4,337	--	--	--	--	--	--	--	--	189	--	4,148	--	--	--
Soft maple	14,195	--	--	--	--	--	--	--	--	2,666	7,210	3,652	619	48	--
Elm	2,315	--	--	--	--	--	--	--	--	110	1,330	300	574	1	--
Ash	5,637	--	--	--	--	--	--	--	--	583	3,205	1,196	655	1	--
Cottonwood	632	--	--	--	--	--	--	--	--	52	364	216	--	--	--
Balsam poplar	431	--	--	--	--	--	--	--	--	--	--	173	258	--	--
Bigtooth aspen	965	--	--	--	--	--	--	--	--	409	--	295	261	--	--
Quaking aspen	2,393	--	--	--	--	--	--	--	9	191	249	277	1,655	12	--
Paper birch	765	--	--	--	--	--	--	--	--	126	--	--	564	75	--
Black cherry	4,193	--	--	--	49	--	--	--	--	1,277	388	1,412	988	--	79
Other hardwoods	2,667	33	--	--	--	--	--	--	14	390	775	1,348	107	--	--
Total	62,421	63	--	143	49	--	--	--	23	21,065	14,678	20,137	5,909	275	79
All species	69,065	554	1,360	1,164	232	--	--	--	102	22,229	15,069	20,868	6,378	278	831

[1] Tables may not add to totals due to rounding.

Table 35.--Average annual yields of growing stock from harvest by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1/]

(In thousand cubic feet)

ALL UNITS

Forest type	All ages	Stand-age class (years)										
		1-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	26,555	--	--	--	12,642	11,971	1,942	--	--	--	--	--
Red pine	30,977	--	--	15,035	14,203	912	424	403	--	--	--	--
White pine	8,533	--	--	--	--	--	--	1,164	1,158	6,211	--	--
White spruce	4,145	--	--	--	232	698	2,415	504	--	296	--	--
Black spruce	11,788	--	--	--	5,924	1,744	4,120	--	--	--	--	--
Balsam fir	28,898	--	--	--	--	17,578	10,099	1,078	143	--	--	--
Tamarack	1,056	--	--	--	111	304	641	--	--	--	--	--
Northern white-cedar	33,391	--	--	--	--	--	--	--	1,280	28,991	3,120	--
Oak-hickory	53,492	--	--	--	--	--	353	28,506	9,265	14,967	401	--
Elm-ash-maple	32,127	--	--	--	--	--	5,093	11,492	10,465	4,753	324	--
Maple-birch	168,188	--	--	--	--	--	--	34,767	25,208	97,190	11,023	--
Aspen	157,349	--	46,568	22,743	65,688	22,350	--	--	--	--	--	--
Paper birch	17,502	--	10	--	268	477	16,679	68	--	--	--	--
Exotic	2,388	--	--	2,388	--	--	--	--	--	--	--	--
All types	576,389	--	46,578	40,166	99,068	56,034	41,766	77,982	47,519	152,408	14,868	--
EASTERN UPPER PENINSULA												
Jack pine	7,388	--	--	--	435	6,953	--	--	--	--	--	--
Red pine	7,448	--	--	1,527	5,921	--	--	--	--	--	--	--
White pine	2,401	--	--	--	--	--	--	--	1,158	1,243	--	--
White spruce	1,176	--	--	--	--	--	672	504	--	--	--	--
Black spruce	6,310	--	--	--	5,924	386	--	--	--	--	--	--
Balsam fir	10,459	--	--	--	--	10,459	--	--	--	--	--	--
Tamarack	447	--	--	--	--	--	447	--	--	--	--	--
Northern white-cedar	16,468	--	--	--	--	--	--	--	1,178	15,290	--	--
Oak-hickory	532	--	--	--	--	--	353	179	--	--	--	--
Elm-ash-maple	3,597	--	--	--	--	--	--	530	2,601	466	--	--
Maple-birch	31,727	--	--	--	--	--	--	--	--	31,727	--	--
Aspen	32,532	--	2,273	3,607	25,470	1,182	--	--	--	--	--	--
Paper birch	5,924	--	--	--	--	477	5,447	--	--	--	--	--
Exotic	112	--	--	112	--	--	--	--	--	--	--	--
All types	126,521	--	2,273	5,246	37,750	19,457	6,919	1,213	4,937	48,726	--	--

(Table 35 continued on next page)

(Table 35 continued)

Forest type	All ages	Stand-age class (years)										
		21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
WESTERN UPPER PENINSULA												
Jack pine	3,036	--	--	--	--	1,094	1,942	--	--	--	--	--
Red pine	3,124	--	--	--	2,297	--	424	403	--	--	--	--
White pine	1,873	--	--	--	--	--	--	--	--	1,873	--	--
White spruce	2,441	--	--	--	--	698	1,743	--	--	--	--	--
Black spruce	4,843	--	--	--	--	849	3,994	--	--	--	--	--
Balsam fir	17,218	--	--	--	--	7,119	10,099	--	--	--	--	--
Tamarack	386	--	--	--	9	304	73	--	--	--	--	--
Northern white-cedar	4,979	--	--	--	--	--	--	--	--	1,859	3,120	--
Oak-hickory	473	--	--	--	--	--	--	--	--	72	401	--
Elm-ash-maple	4,611	--	--	--	--	--	--	--	--	4,287	324	--
Maple-birch	72,885	--	--	--	--	--	--	--	--	61,862	11,023	--
Aspen	40,127	--	--	--	18,959	21,168	--	--	--	--	--	--
Paper birch	6,592	--	--	--	--	--	6,592	--	--	--	--	--
All types	162,588	--	--	--	21,265	31,232	24,867	403	--	69,953	14,868	--
NORTHERN LOWER PENINSULA												
Jack pine	15,577	--	--	--	12,207	3,370	--	--	--	--	--	--
Red pine	19,045	--	--	13,508	5,537	--	--	--	--	--	--	--
White pine	3,095	--	--	--	--	--	--	--	--	3,095	--	--
White spruce	296	--	--	--	--	--	--	--	--	296	--	--
Black spruce	635	--	--	--	--	509	126	--	--	--	--	--
Balsam fir	1,221	--	--	--	--	--	--	1,078	143	--	--	--
Tamarack	223	--	--	--	102	--	121	--	--	--	--	--
Northern white-cedar	11,842	--	--	--	--	--	--	--	--	11,842	--	--
Oak-hickory	30,258	--	--	--	--	--	--	28,327	1,931	--	--	--
Elm-ash-maple	8,850	--	--	--	--	--	--	4,668	4,182	--	--	--
Maple-birch	42,708	--	--	--	--	--	--	29,645	13,063	--	--	--
Aspen	78,312	--	42,629	16,058	19,625	--	--	--	--	--	--	--
Paper birch	4,708	--	--	--	--	--	4,640	68	--	--	--	--
Exotic	1,445	--	--	1,445	--	--	--	--	--	--	--	--
All types	218,215	--	42,629	31,011	37,471	3,879	4,887	63,786	19,319	15,233	--	--
SOUTHERN LOWER PENINSULA												
Jack pine	554	--	--	--	--	554	--	--	--	--	--	--
Red pine	1,360	--	--	--	448	912	--	--	--	--	--	--
White pine	1,164	--	--	--	--	--	--	1,164	--	--	--	--
White spruce	232	--	--	--	232	--	--	--	--	--	--	--
Northern white-cedar	102	--	--	--	--	--	--	--	102	--	--	--
Oak-hickory	22,229	--	--	--	--	--	--	--	7,334	14,895	--	--
Elm-ash-maple	15,069	--	--	--	--	--	5,093	6,294	3,682	--	--	--
Maple-birch	20,868	--	--	--	--	--	--	5,122	12,145	3,601	--	--
Aspen	6,378	--	1,666	3,078	1,634	--	--	--	--	--	--	--
Paper birch	278	--	10	--	268	--	--	--	--	--	--	--
Exotic	831	--	--	831	--	--	--	--	--	--	--	--
All types	69,065	--	1,676	3,909	2,582	1,466	5,093	12,580	23,263	18,496	--	--

[1] Tables may not add to totals due to rounding.

Table 36.--Commercial forest area qualifying for thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand acres)

ALL UNITS

Forest type	All ages	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
Red pine	134.8	--	13.1	74.1	47.5	--	--	--	--
White pine	2.9	--	--	--	2.9	--	--	--	--
White spruce	1.2	--	--	--	1.2	--	--	--	--
Oak-hickory	98.6	--	53.6	31.2	13.8	--	--	--	--
Maple-birch	2,363.4	--	206.3	200.5	151.9	289.6	781.2	733.8	--
All types	2,600.7	--	273.1	305.8	217.3	289.6	781.2	733.8	--
EASTERN UPPER PENINSULA									
Red pine	17.0	--	--	14.9	2.1	--	--	--	--
White spruce	1.2	--	--	--	1.2	--	--	--	--
Maple-birch	431.8	--	31.3	45.1	34.3	52.7	155.6	112.7	--
All types	449.9	--	31.3	60.0	37.6	52.7	155.6	112.7	--
WESTERN UPPER PENINSULA									
Red pine	22.0	--	--	13.9	8.1	--	--	--	--
Oak-hickory	1.6	--	--	--	1.6	--	--	--	--
Maple-birch	906.5	--	44.1	53.6	48.8	107.4	332.7	320.0	--
All types	930.1	--	44.1	67.5	58.5	107.4	332.7	320.0	--
NORTHERN LOWER PENINSULA									
Red pine	88.3	--	13.1	40.5	34.7	--	--	--	--
Oak-hickory	60.1	--	41.2	6.8	12.2	--	--	--	--
Maple-birch	724.5	--	47.6	48.4	35.2	80.6	237.6	275.1	--
All types	872.9	--	101.9	95.7	82.1	80.6	237.6	275.1	--
SOUTHERN LOWER PENINSULA									
Red pine	7.4	--	--	4.8	2.6	--	--	--	--
White pine	2.9	--	--	--	2.9	--	--	--	--
Oak-hickory	36.9	--	12.4	24.5	--	--	--	--	--
Maple-birch	300.6	--	83.4	53.4	33.6	48.9	55.3	26.0	--
All types	347.8	--	95.8	82.7	39.1	48.9	55.3	26.0	--

[1] Tables may not add to totals due to rounding.

Table 37.--Average annual yields from thinning by species group, tree class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
			ALL UNITS			
SOFTWOODS						
Jack pine	1,266	236	1,030	8	--	8
Red pine	16,494	4,135	12,359	244	--	244
White pine	3,519	633	2,886	94	--	94
White spruce	2,615	307	2,308	--	--	--
Black spruce	138	117	21	--	--	--
Balsam fir	4,269	2,344	1,925	15	--	15
Hemlock	2,231	149	2,082	63	13	50
Tamarack	5	--	5	--	--	--
Northern white-cedar	574	174	400	--	--	--
Other softwoods	443	245	198	--	--	--
Total	31,554	8,340	23,214	424	13	411
HARDWOODS						
White oak	887	222	665	--	--	--
Select red oak	2,908	403	2,505	151	80	71
Other red oak	415	57	358	85	--	85
Hickory	380	137	243	28	--	28
Basswood	20,878	1,878	19,000	637	191	446
Beech	842	589	253	12	--	12
Yellow birch	1,050	633	417	7	--	7
Hard maple	42,095	28,388	13,707	1,424	237	1187
Soft maple	26,070	12,123	13,947	886	86	800
Elm	6,326	1,639	4,687	200	21	179
Ash	4,761	2,546	2,215	122	68	54
Cottonwood	518	34	484	--	--	--
Balsam poplar	188	32	156	--	--	--
Bigtooth aspen	3,288	1,576	1,712	22	15	7
Quaking aspen	6,890	1,336	5,554	483	39	444
Paper birch	2,267	692	1,575	66	9	57
Black cherry	7,390	2,612	4,778	542	57	485
Other hardwoods	1,863	1,236	627	40	--	40
Total	129,016	56,133	72,883	4,705	803	3,902
All species	160,570	64,473	96,097	5,129	816	4,313
			EASTERN UPPER PENINSULA			
SOFTWOODS						
Jack pine	54	--	54	--	--	--
Red pine	2,014	46	1,968	17	--	17
White pine	492	55	437	--	--	--
White spruce	959	229	730	--	--	--
Black spruce	138	117	21	--	--	--
Balsam fir	1,456	774	682	--	--	--
Hemlock	395	120	275	13	13	--
Northern white-cedar	86	36	50	--	--	--
Total	5,594	1,377	4,217	30	13	17
HARDWOODS						
Select red oak	80	--	80	16	16	--
Basswood	3,103	136	2,967	8	--	8
Beech	267	204	63	--	--	--
Yellow birch	204	88	116	--	--	--
Hard maple	8,900	4,987	3,913	345	75	270
Soft maple	5,543	2,838	2,705	218	35	183
Elm	827	228	599	51	--	51
Ash	202	43	159	11	11	--
Balsam poplar	34	--	34	--	--	--
Bigtooth aspen	118	16	102	--	--	--
Quaking aspen	331	98	233	--	--	--
Paper birch	330	70	260	42	9	33
Black cherry	1,171	543	628	116	--	116
Total	21,110	9,251	11,859	807	146	661
All species	26,704	10,628	16,076	837	159	678

(Table 37 continued on next page)

(Table 37 continued)

WESTERN UPPER PENINSULA

Species group	Tree class					
	Growing stock			Cull		
	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2/]
SOFTWOODS						
Red pine	2,348	908	1,440	11	--	11
White pine	409	--	409	--	--	--
White spruce	1,617	39	1,578	--	--	--
Balsam fir	2,601	1,421	1,180	15	--	15
Hemlock	1,217	13	1,204	50	--	50
Northern white-cedar	229	14	215	--	--	--
Total	8,421	2,395	6,026	76	--	76
HARDWOODS						
Select red oak	447	98	349	35	21	14
Basswood	11,257	1,063	10,194	354	163	191
Yellow birch	705	432	273	7	--	7
Hard maple	16,584	11,760	4,824	834	85	749
Soft maple	7,414	3,609	3,805	209	13	196
Elm	2,776	434	2,342	149	21	128
Ash	518	284	234	17	--	17
Balsam poplar	154	32	122	--	--	--
Bigtooth aspen	469	163	306	--	--	--
Quaking aspen	3,386	314	3,072	342	22	320
Paper birch	740	250	490	24	--	24
Black cherry	917	425	492	6	--	6
Total	45,367	18,864	26,503	1,977	325	1,652
All species	53,788	21,259	32,529	2,053	325	1,728
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Jack pine	1,212	236	976	8	--	8
Red pine	11,222	2962	8,260	40	--	40
White pine	2,087	436	1,651	35	--	35
White spruce	39	39	--	--	--	--
Balsam fir	212	149	63	--	--	--
Hemlock	619	16	603	--	--	--
Tamarack	5	--	5	--	--	--
Northern white-cedar	259	124	135	--	--	--
Other softwoods	23	--	23	--	--	--
Total	15,678	3,962	11,716	83	--	83
HARDWOODS						
White oak	266	131	135	--	--	--
Select red oak	2,018	273	1,745	57	--	57
Other red oak	331	57	274	85	--	85
Basswood	5,785	545	5,240	115	28	87
Beech	524	334	190	12	--	12
Yellow birch	93	65	28	--	--	--
Hard maple	14,415	9,710	4,705	245	77	168
Soft maple	9,159	4,131	5,028	403	38	365
Elm	810	141	669	--	--	--
Ash	1,360	414	946	19	--	19
Bigtooth aspen	2,396	1,148	1,248	22	15	7
Quaking aspen	2,751	750	2,001	141	17	124
Paper birch	1,014	285	729	--	--	--
Black cherry	1,886	239	1,647	308	57	251
Other hardwoods	277	144	133	--	--	--
Total	43,085	18,367	24,718	1,407	232	1,175
All species	58,763	22,329	36,434	1,490	232	1,258

(Table 37 continued on next page)

[illegible]

SOUTHERN LOWER PENINSULA

Species group	Tree class					
	Growing stock			Cull		
	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
SOFTWOODS						
Red pine	910	219	691	176	--	176
White pine	531	142	389	59	--	59
Other softwoods	420	245	175	--	--	--
Total	1,861	606	1,255	235	--	235
HARDWOODS						
White oak	621	91	530	--	--	--
Select red oak	363	32	331	43	43	--
Other red oak	84	--	84	--	--	--
Hickory	380	137	243	28	--	28
Basswood	733	134	599	160	--	160
Beech	51	51	--	--	--	--
Yellow birch	48	48	--	--	--	--
Hard maple	2,196	1,931	265	--	--	--
Soft maple	3,954	1,545	2,409	56	--	56
Elm	1,913	836	1,077	--	--	--
Ash	2,681	1,805	876	75	57	18
Cottonwood	518	34	484	--	--	--
Bigtooth aspen	305	249	56	--	--	--
Quaking aspen	422	174	248	--	--	--
Paper birch	183	87	96	--	--	--
Black cherry	3,416	1,405	2,011	112	--	112
Other hardwoods	1,586	1,092	494	40	--	40
Total	19,454	9,651	9,803	514	100	414
All species	21,315	10,257	11,058	749	100	649

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 38.--Average annual yields of growing stock from thinning by species group, forest type, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

		Forest type[2]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
ALL UNITS							
SOFTWOODS							
Jack pine	1,266	1,028	--	--	--	84	154
Red pine	16,494	14,408	--	178	--	843	1,065
White pine	3,519	177	142	--	--	--	3,200
White spruce	2,615	--	--	--	--	--	2,615
Black spruce	138	--	--	--	--	--	138
Balsam fir	4,269	281	--	--	--	--	3,988
Hemlock	2,231	--	--	--	--	--	2,231
Tamarack	5	--	--	--	--	--	5
Northern white-cedar	574	--	--	--	--	--	574
Other softwoods	443	--	--	--	--	--	443
Total	31,554	15,894	142	178	--	927	14,413
HARDWOODS							
White oak	887	112	--	--	--	215	560
Select red oak	2,908	--	--	--	--	497	2,411
Other red oak	415	99	--	--	--	316	--
Hickory	380	--	--	--	--	81	299
Basswood	20,878	--	--	--	--	--	20,878
Beech	842	--	--	--	--	42	800
Yellow birch	1,050	--	--	--	--	--	1,050
Hard maple	42,095	89	--	--	--	--	42,006
Soft maple	26,070	--	--	--	--	1,188	24,882
Elm	6,326	--	--	--	--	21	6,305
Ash	4,761	--	--	--	--	56	4,705
Cottonwood	518	--	--	--	--	--	518
Balsam poplar	188	--	--	--	--	--	188
Bigtooth aspen	3,288	216	--	--	--	217	2,855
Quaking aspen	6,890	993	--	--	--	423	5,474
Paper birch	2,267	17	--	--	--	--	2,250
Black cherry	7,390	22	--	--	--	1,137	6,231
Other hardwoods	1,863	93	--	--	--	158	1,612
Total	129,016	1,641	--	--	--	4,351	123,024
All species	160,570	17,535	142	178	--	5,278	137,437
EASTERN UPPER PENINSULA							
SOFTWOODS							
Jack pine	54	54	--	--	--	--	--
Red pine	2,014	1,815	--	178	--	--	21
White pine	492	--	--	--	--	--	492
White spruce	959	--	--	--	--	--	959
Black spruce	138	--	--	--	--	--	138
Balsam fir	1,456	177	--	--	--	--	1,279
Hemlock	395	--	--	--	--	--	395
Northern white-cedar	86	--	--	--	--	--	86
Total	5,594	2,046	--	178	--	--	3,370
HARDWOODS							
Select red oak	80	--	--	--	--	--	80
Basswood	3,103	--	--	--	--	--	3,103
Beech	267	--	--	--	--	--	267
Yellow birch	204	--	--	--	--	--	204
Hard maple	8,900	--	--	--	--	--	8,900
Soft maple	5,543	--	--	--	--	--	5,543
Elm	827	--	--	--	--	--	827
Ash	202	--	--	--	--	--	202
Balsam poplar	34	--	--	--	--	--	34
Bigtooth aspen	118	--	--	--	--	--	118
Quaking aspen	331	--	--	--	--	--	331
Paper birch	330	--	--	--	--	--	330
Black cherry	1,171	--	--	--	--	--	1,171
Total	21,110	--	--	--	--	--	21,110
All species	26,704	2,046	--	178	--	--	24,480

(Table 38 continued on next page)

(Table 38 continued)

WESTERN UPPER PENINSULA

		Forest type[2]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Red pine	2,348	2,256	--	--	--	92	--
White pine	409	--	--	--	--	--	409
White spruce	1,617	--	--	--	--	--	1,617
Balsam fir	2,601	--	--	--	--	--	2,601
Hemlock	1,217	--	--	--	--	--	1,217
Northern white-cedar	229	--	--	--	--	--	229
Total	8,421	2,256	--	--	--	92	6,073
HARDWOODS							
Select red oak	447	--	--	--	--	--	447
Basswood	11,257	--	--	--	--	--	11,257
Yellow birch	705	--	--	--	--	--	705
Hard maple	16,584	--	--	--	--	--	16,584
Soft maple	7,414	--	--	--	--	--	7,414
Elm	2,776	--	--	--	--	--	2,776
Ash	518	--	--	--	--	--	518
Balsam poplar	154	--	--	--	--	--	154
Bigtooth aspen	469	--	--	--	--	--	469
Quaking aspen	3,386	161	--	--	--	--	3,225
Paper birch	740	17	--	--	--	--	723
Black cherry	917	--	--	--	--	--	917
Total	45,367	178	--	--	--	--	45,189
All species	53,788	2,434	--	--	--	92	51,262

NORTHERN LOWER PENINSULA

		Forest type[2]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Jack pine	1,212	974	--	--	--	84	154
Red pine	11,222	9,427	--	--	--	751	1,044
White pine	2,087	177	--	--	--	--	1,910
White spruce	39	--	--	--	--	--	39
Balsam fir	212	104	--	--	--	--	108
Hemlock	619	--	--	--	--	--	619
Tamarack	5	--	--	--	--	--	5
Northern white-cedar	259	--	--	--	--	--	259
Other softwoods	23	--	--	--	--	--	23
Total	15,678	10,682	--	--	--	835	4,161
HARDWOODS							
White oak	266	--	--	--	--	97	169
Select red oak	2,018	--	--	--	--	439	1,579
Other red oak	331	99	--	--	--	232	0
Basswood	5,785	--	--	--	--	--	5,785
Beech	524	--	--	--	--	42	482
Yellow birch	93	--	--	--	--	--	93
Hard maple	14,415	89	--	--	--	--	14,326
Soft maple	9,159	--	--	--	--	1,188	7,971
Elm	810	--	--	--	--	--	810
Ash	1,360	--	--	--	--	--	1,360
Bigtooth aspen	2,396	216	--	--	--	217	1,963
Quaking aspen	2,751	832	--	--	--	130	1,789
Paper birch	1,014	--	--	--	--	--	1,014
Black cherry	1,886	22	--	--	--	111	1,753
Other hardwoods	277	--	--	--	--	158	119
Total	43,085	1,258	--	--	--	2,614	39,213
All species	58,763	11,940	--	--	--	3,449	43,374

(Table 38 continued on next page)

(Table 38 continued)

SOUTHERN LOWER PENINSULA

		Forest type[2]					
Species group	Total	Red pine	White pine	White spruce	Balsam fir	Oak-hickory	Maple-birch
SOFTWOODS							
Red pine	910	910	--	--	--	--	--
White pine	531	--	142	--	--	--	389
Other softwoods	420	--	--	--	--	--	420
Total	1,861	910	142	--	--	--	809
HARDWOODS							
White oak	621	112	--	--	--	118	391
Select red oak	363	--	--	--	--	58	305
Other red oak	84	--	--	--	--	84	--
Hickory	380	--	--	--	--	81	299
Basswood	733	--	--	--	--	--	733
Beech	51	--	--	--	--	--	51
Yellow birch	48	--	--	--	--	--	48
Hard maple	2,196	--	--	--	--	--	2,196
Soft maple	3,954	--	--	--	--	--	3,954
Elm	1,913	--	--	--	--	21	1,892
Ash	2,681	--	--	--	--	56	2,625
Cottonwood	518	--	--	--	--	--	518
Bigtooth aspen	305	--	--	--	--	--	305
Quaking aspen	422	--	--	--	--	293	129
Paper birch	183	--	--	--	--	--	183
Black cherry	3,416	--	--	--	--	1,026	2,390
Other hardwoods	1,586	93	--	--	--	--	1,493
Total	19,454	205	--	--	--	1,737	17,512
All species	21,315	1,115	142	--	--	1,737	18,321

[1] Tables may not add to totals due to rounding.

[2] Thinning was treatment option only in the forest types shown below.

Table 39.--Average annual yields of growing stock from thinning by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

		Stand-age class (years)							
Forest type	All ages	1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
ALL UNITS									
Red pine	17,535	--	2,176	8,465	6,894	--	--	--	--
White pine	142	--	--	--	142	--	--	--	--
White spruce	178	--	--	--	178	--	--	--	--
Oak-hickory	5,278	--	3,772	1,036	470	--	--	--	--
Maple-birch	137,437	--	13,056	12,088	8,646	19,053	43,469	41,125	--
All types	160,570	--	19,004	21,589	16,330	19,053	43,469	41,125	--
EASTERN UPPER PENINSULA									
Red pine	2,046	--	--	1,678	368	--	--	--	--
White spruce	178	--	--	--	178	--	--	--	--
Maple-birch	24,480	--	2,095	2,399	2,081	3,888	7,957	6,060	--
All types	26,704	--	2,095	4,077	2,627	3,888	7,957	6,060	--
WESTERN UPPER PENINSULA									
Red pine	2,434	--	--	1,084	1,350	--	--	--	--
Oak-hickory	92	--	--	--	92	--	--	--	--
Maple-birch	51,262	--	2,184	3,250	2,553	6,813	18,491	17,971	--
All types	53,788	--	2,184	4,334	3,995	6,813	18,491	17,971	--
NORTHERN LOWER PENINSULA									
Red pine	11,940	--	2,176	5,082	4,682	--	--	--	--
Oak-hickory	3,449	--	2,912	159	378	--	--	--	--
Maple-birch	43,374	--	3,502	2,797	1,985	5,076	14,405	15,609	--
All types	58,763	--	8,590	8,038	7,045	5,076	14,405	15,609	--
SOUTHERN LOWER PENINSULA									
Red pine	1,115	--	--	621	494	--	--	--	--
White pine	142	--	--	--	142	--	--	--	--
Oak-hickory	1,737	--	860	877	--	--	--	--	--
Maple-birch	18,321	--	5,275	3,642	2,027	3,276	2,616	1,485	--
All types	21,315	--	6,135	5,140	2,663	3,276	2,616	1,485	--

[1] Tables may not add to totals due to rounding.

Table 40.--Commercial forest area qualifying for timber stand improvement by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand acres)

ALL UNITS

Forest type	Total	Stand-age class (years)							
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81+
Jack pine	6.8	--	4.6	2.3	--	--	--	--	--
Red pine	0.8	--	--	0.8	--	--	--	--	--
White pine	5.8	--	5.8	--	--	--	--	--	--
White spruce	11.2	--	3.7	7.5	--	--	--	--	--
Balsam fir	14.2	--	1.6	12.5	--	--	--	--	--
Northern white-cedar	56.1	--	--	--	56.1	--	--	--	--
Oak-hickory	21.6	--	11.0	10.5	--	--	--	--	--
Maple-birch	200.2	--	40.1	44.2	14.3	28.3	30.7	42.6	--
All types	316.6	--	66.8	77.8	70.4	28.3	30.7	42.6	--
EASTERN UPPER PENINSULA									
White pine	3.6	--	3.6	--	--	--	--	--	--
White spruce	4.7	--	1.5	3.2	--	--	--	--	--
Balsam fir	5.3	--	--	5.3	--	--	--	--	--
Northern white-cedar	37.1	--	--	--	37.1	--	--	--	--
Maple-birch	49.7	--	6.5	7.5	2.9	12.9	6.0	13.8	--
All types	100.3	--	11.6	16.0	40.0	12.9	6.0	13.8	--
WESTERN UPPER PENINSULA									
White spruce	1.6	--	--	1.6	--	--	--	--	--
Balsam fir	6.6	--	1.6	4.9	--	--	--	--	--
Northern white-cedar	8.4	--	--	--	8.4	--	--	--	--
Maple-birch	74.3	--	8.1	16.0	1.6	9.8	15.1	23.8	--
All types	90.9	--	9.7	22.5	10.0	9.8	15.1	23.8	--
NORTHERN LOWER PENINSULA									
Jack pine	6.8	--	4.6	2.3	--	--	--	--	--
Red pine	0.8	--	--	0.8	--	--	--	--	--
White pine	2.2	--	2.2	--	--	--	--	--	--
White spruce	4.9	--	2.2	2.7	--	--	--	--	--
Balsam fir	2.3	--	--	2.3	--	--	--	--	--
Northern white-cedar	7.3	--	--	--	7.3	--	--	--	--
Oak-hickory	10.7	--	3.5	7.1	--	--	--	--	--
Maple-birch	41.8	--	8.7	9.1	7.2	2.2	9.6	5.0	--
All types	76.8	--	21.2	24.3	14.5	2.2	9.6	5.0	--
SOUTHERN LOWER PENINSULA									
Northern white-cedar	3.3	--	--	--	3.3	--	--	--	--
Oak-hickory	10.9	--	7.5	3.4	--	--	--	--	--
Maple-birch	34.4	--	16.8	11.6	2.6	3.4	--	--	--
All types	48.6	--	24.3	15.0	5.9	3.4	--	--	--

---

[1] Tables may not add to totals due to rounding.

Table 41.--Average annual yields from timber stand improvement by species group tree class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

	Tree class					
	Growing stock			Cull		
Species group	Total	Pole-timber	Saw-timber	Total	Shortlog	Other[2]
ALL UNITS						
SOFTWOODS						
Red pine	101	--	101	--	--	--
White pine	169	--	169	25	--	25
White spruce	1,094	--	1,094	--	--	--
Black spruce	28	--	28	--	--	--
Balsam fir	1,163	787	376	--	--	--
Total	2,555	787	1,768	25	--	25
HARDWOODS						
Soft maple	107	--	107	--	--	--
Balsam poplar	53	42	11	8	--	8
Bigtooth aspen	57	--	57	--	--	--
Quaking aspen	535	194	341	36	--	36
Total	752	236	516	44	--	44
All species	3,307	1,023	2,284	69	--	69
EASTERN UPPER PENINSULA						
SOFTWOODS						
White pine	122	--	122	25	--	25
White spruce	49	--	49	--	--	--
Balsam fir	753	617	136	--	--	--
Total	924	617	307	25	--	25
HARDWOODS						
Soft maple	107	--	107	--	--	--
Balsam poplar	33	22	11	8	--	8
Bigtooth aspen	57	--	57	--	--	--
Quaking aspen	223	110	113	23	--	23
Total	420	132	288	31	--	31
All species	1,344	749	595	56	--	56
WESTERN UPPER PENINSULA						
SOFTWOODS						
Balsam fir	117	97	20	--	--	--
Total	117	97	20	--	--	--
HARDWOODS						
Balsam poplar	20	20	--	--	--	--
Quaking aspen	189	84	105	--	--	--
Total	209	104	105	--	--	--
All species	326	201	125	--	--	--
NORTHERN LOWER PENINSULA						
SOFTWOODS						
Red pine	101	--	101	--	--	--
White pine	47	--	47	--	--	--
White spruce	1,045	--	1,045	--	--	--
Black spruce	28	--	28	--	--	--
Balsam fir	293	73	220	--	--	--
Total	1,514	73	1,441	--	--	--
HARDWOODS						
Quaking aspen	123	--	123	13	--	13
Total	123	--	123	13	--	13
All species	1,637	73	1,564	13	--	13
SOUTHERN LOWER PENINSULA						
SOFTWOODS						
Total	--	--	--	--	--	--
HARDWOODS						
Total	--	--	--	--	--	--
All species	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

[2] Rough and rotten cull.

Table 42.--Average annual yields of growing stock from timber stand improvement by species group, forest type, and Forest Survey Unit, Michigan 2001-2010[1]

(In thousand cubic feet)

		Forest type[2]							
Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak-hickory	Maple-birch
ALL UNITS									
SOFTWOODS									
Red pine	101	--	--	101	--	--	--	--	--
White pine	169	--	--	169	--	--	--	--	--
White spruce	1,094	--	--	--	1,094	--	--	--	--
Black spruce	28	--	--	--	28	--	--	--	--
Balsam fir	1,163	--	--	--	214	--	949	--	--
Total	2,555	--	--	270	1,336	--	949	--	--
HARDWOODS									
Soft maple	107	--	--	107	--	--	--	--	--
Balsam poplar	53	--	--	--	--	--	53	--	--
Bigtooth aspen	57	--	--	--	--	57	--	--	--
Quaking aspen	535	--	--	--	33	417	85	--	--
Total	752	--	--	107	33	474	138	--	--
All species	3,307	--	--	377	1,369	474	1,087	--	--
EASTERN UPPER PENINSULA									
SOFTWOODS									
White pine	122	--	--	122	--	--	--	--	--
White spruce	49	--	--	--	49	--	--	--	--
Balsam fir	753	--	--	--	--	--	753	--	--
Total	924	--	--	122	49	--	753	--	--
HARDWOODS									
Soft maple	107	--	--	107	--	--	--	--	--
Balsam poplar	33	--	--	--	--	--	33	--	--
Bigtooth aspen	57	--	--	--	--	57	--	--	--
Quaking aspen	223	--	--	--	33	120	70	--	--
Total	420	--	--	107	33	177	103	--	--
All species	1,344	--	--	229	82	177	856	--	--
WESTERN UPPER PENINSULA									
SOFTWOODS									
Balsam fir	117	--	--	--	--	--	117	--	--
Total	117	--	--	--	--	--	117	--	--
HARDWOODS									
Balsam poplar	20	--	--	--	--	--	20	--	--
Quaking aspen	189	--	--	--	--	189	--	--	--
Total	209	--	--	--	--	189	20	--	--
All species	326	--	--	--	--	189	137	--	--

(Table 42 continued on next page)

(Table 42 continued)

NORTHERN LOWER PENINSULA

Species group	All types	Forest type[2]							
		Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak-hickory	Maple-birch
SOFTWOODS									
Red pine	101	--	--	101	--	--	--	--	--
White pine	47	--	--	47	--	--	--	--	--
White spruce	1,045	--	--	--	1,045	--	--	--	--
Black spruce	28	--	--	--	28	--	--	--	--
Balsam fir	293	--	--	--	214	--	79	--	--
Total	1,514	--	--	148	1,287	--	79	--	--
HARDWOODS									
Quaking aspen	123	--	--	--	--	108	15	--	--
Total	123	--	--	--	--	108	15	--	--
All species	1,637	--	--	148	1,287	108	94	--	--

SOUTHERN LOWER PENINSULA

Species group	All types	Jack pine	Red pine	White pine	White spruce	Balsam fir	Northern white-cedar	Oak-hickory	Maple-birch
SOFTWOODS									
Total	--	--	--	--	--	--	--	--	--
HARDWOODS								--	--
Total	--	--	--	--	--	--	--	--	--
All species	--	--	--	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

[2] Timber stand improvement was a treatment option only in the forest types shown below.

Table 43.--Average annual yields of growing stock from timber stand improvement by forest type, stand-age class, and Forest Survey Unit, Michigan, 2001-2010[1]

(In thousand cubic feet)

	All	Stand-age class (years)				
Forest type	ages	1-20	21-30	31-40	41-50	51+
ALL UNITS						
White pine	377	--	377	--	--	--
White spruce	1,369	--	586	783	--	--
Balsam fir	474	--	--	474	--	--
Northern white-cedar	1,087	--	--	--	1,087	--
All types	3,307	--	963	1,257	1,087	--
EASTERN UPPER PENINSULA						
White pine	229	--	229	--	--	--
White spruce	82	--	33	49	--	--
Balsam fir	177	--	--	177	--	--
Northern white-cedar	856	--	--	--	856	--
All types	1,344	--	262	226	856	--
WESTERN UPPER PENINSULA						
Balsam fir	189	--	--	189	--	--
Northern white-cedar	137	--	--	--	137	--
All types	326	--	--	189	137	--
NORTHERN LOWER PENINSULA						
White pine	148	--	148	--	--	--
White spruce	1,287	--	553	734	--	--
Balsam fir	108	--	--	108	--	--
Northern white-cedar	94	--	--	--	94	--
All types	1,637	--	701	842	94	--
SOUTHERN LOWER PENINSULA						
All types	--	--	--	--	--	--

[1] Tables may not add to totals due to rounding.

Table 44.--Average annual yields of growing stock from harvest by species group, tree class, and Forest Survey Unit, Michigan, 1979 and estimated 1981-1990[1]

(In thousand cubic feet)

Species group	All Units		Eastern Upper Peninsula		Western Upper Peninsula		Northern Lower Peninsula		Southern Lower Peninsula	
	Reported 1979 removals	Stems estimated 1981-1990 avg. annual removals	Reported 1979 removals	Stems estimated 1981-1990 avg. annual removals	Reported 1979 removals	Stems estimated 1981-1990 avg. annual removals	Reported 1979 removals	Stems estimated 1981-1990 avg. annual removals	Reported 1979 removals	Stems estimated 1981-1990 avg. annual removals
SOFTWOODS										
Jack pine	16,192	15,300	5,230	4,300	2,889	2,197	7,999	8,457	74	346
Red pine	7,798	16,116	1,422	3,497	1,945	2,011	3,105	9,797	1,326	811
White pine	5,097	20,208	1,691	4,819	2,409	5,474	872	7,489	125	2,426
White spruce	2,194	10,721	997	2,917	1,100	6,134	87	1,670	10	--
Black spruce	2,441	5,503	1,432	3,364	921	1,691	88	448	--	--
Balsam fir	8,931	19,119	4,273	6,365	3,816	9,312	842	3,442	--	--
Hemlock	6,633	14,573	2,554	3,909	3,868	7,582	185	2,699	26	383
Tamarack	772	1,458	151	583	79	454	438	334	104	87
Northern white-cedar	6,088	36,230	3,396	14,709	976	9,968	1,633	11,369	83	184
Other softwoods	221	1,513	--	--	--	--	--	904	221	609
Total	56,367	140,741	21,146	44,463	18,003	44,823	15,249	46,609	1,969	4,846
HARDWOODS										
White oak	8,984	11,761	17	--	23	95	3,006	5,543	5,938	6,123
Select red oak	20,599	28,859	151	374	1,417	2,093	11,720	17,888	7,311	8,504
Other red oak	6,073	4,099	--	--	--	--	3,541	2,596	2,532	1,503
Hickory	647	1,804	--	--	--	--	15	37	632	1,767
Basswood	4,794	8,787	482	224	1,153	1,268	1,980	4,765	1,179	2,530
Beech	5,840	8,459	3,444	4,166	101	25	1,539	3,185	756	1,083
Yellow birch	4,894	10,154	1,616	2,821	3,224	6,143	40	999	14	191
Hard maple	32,271	46,786	9,179	6,390	14,549	23,529	5,310	13,602	3,233	3,265
Soft maple	23,982	45,197	3,189	8,837	6,075	9,901	8,839	16,605	5,879	9,854
Elm	6,997	3,329	1,289	402	3,351	1,677	1,731	281	626	969
Ash	5,614	12,650	313	905	547	2,389	2,090	5,367	2,664	3,989
Cottonwood	1,291	2,390	--	--	--	18	454	384	837	1,988
Balsam poplar	2,370	8,946	926	2,876	651	1,435	784	4,294	9	341
Bigtooth aspen	31,390	30,512	1,509	2,158	3,792	2,676	25,206	23,189	883	2,489
Quaking aspen	51,805	47,639	8,658	10,066	22,510	15,121	20,023	20,737	614	1,715
Paper birch	7,734	19,978	2,471	5,875	2,574	6,672	2,579	7,198	110	233
Other hardwoods[2]	2,944	5,780	108	264	332	837	418	1,960	2,086	2,719
Total	218,229	297,130	33,352	45,358	60,299	73,879	89,275	128,630	35,303	49,263
All species	274,596	437,871	54,498	89,821	78,302	118,702	104,524	175,239	37,272	54,109

[1] Table may not add to totals due to rounding.

[2] Includes black cherry.

Jakes, Pamela J., Smith, W. Brad.
Michigan's predicted timber yields 1981-2010. Res. Pap. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 98 p.

Provides a view of the timber supply potential for Michigan during the period 1981-2010. Forest management areas and timber volume statistics are presented for each survey unit in the State.

KEY WORDS: Area, timber supply, timber harvest, timber removals, STEMS.

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Future Consumption of Timber Growth in Northern Minnesota: 1980-2030

Mark Rockel, Joseph Buongiorno,
David C. Lothner and Edwin Kallio

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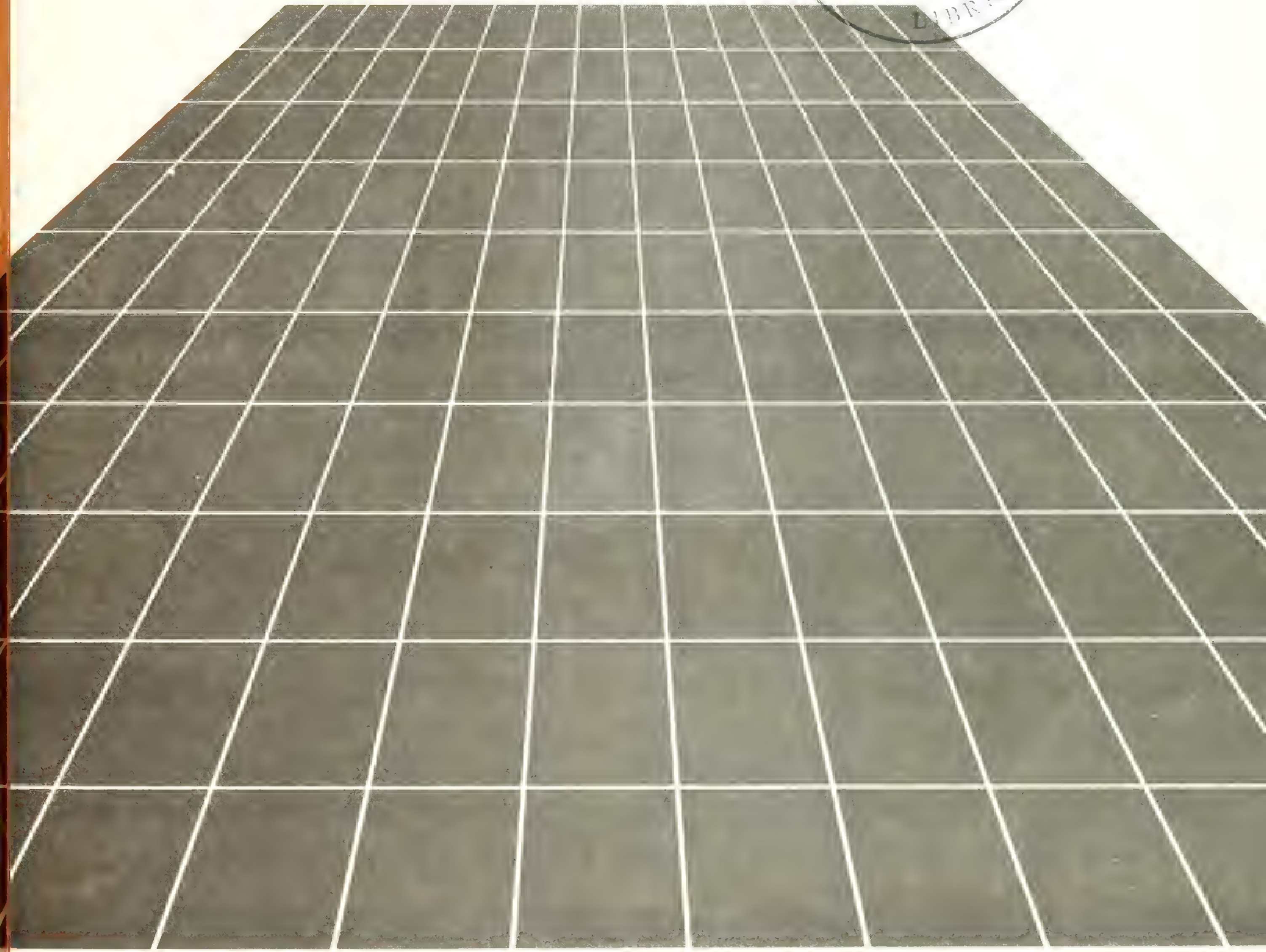

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FUTURE CONSUMPTION OF TIMBER GROWN IN NORTHERN MINNESOTA 1980-2030[1]

Mark Rockel, *Former Research Specialist,*
Joseph Buongiorno, *Associate Professor,*
Department of Forestry, University of Wisconsin,
Madison, Wisconsin,
David C. Lothner, *Principal Economist,*
and **Edwin Kallio,** *Principal Market Analyst,*
North Central Forest Experiment Station,
Duluth, Minnesota

The timber harvest of northern Minnesota[2] has always been a significant portion of the total State harvest. In 1975 the roundwood harvest in northern Minnesota was slightly more than 137 million cubic feet (1.73 million cords), which is nearly 87 percent of the total Minnesota roundwood harvest. Pulpwood is the largest component of the northern Minnesota harvest. Production has grown steadily, from 748 thousand cords in 1950 to 1.17 million cords in 1976.

Eight pulp mills in Minnesota and several mills in neighboring Wisconsin and Ontario presently consume wood harvested from this region. In addition, three flakeboard mills are currently purchasing pulpwood-size materials from this area. Another mill has been completed, but awaits start-up.

With the growth of wood using industries and fuelwood markets in Minnesota, both public agencies and private industries are concerned about the future demand for roundwood. The National Forest Management Act of 1976 (NFMA), the Rules for Carrying Out the Act in 1979, and the Boundary Waters Canoe Wilderness Act of 1979 (BWCWA) have specific provisions for determining future demand for harvested timber. The NFMA and the implementation rules require the individual national forests to estimate the present and future demands for timber from the forests so that they can plan their production activities. With the passage of the BWCWA, additional concern has risen regarding the future supply of commercially harvestable timber as more northern Minnesota forest land has been allocated for recreation.

The purpose of this paper is to present long-term projections of consumption for pulpwood, fuelwood, and saw logs grown in northern Minnesota. The latest Forest Service analysis of the timber situation in the United States (USDA Forest Service 1980) serves as the basis for the projections. We attempt to determine the implications of the Forest Service national and regional (North-Central) projections for northern Minnesota. For that reason, the basic projection interval (1980-2030) used in the national analysis is used here, as well as the same basic assumptions regarding demographic, economic, and construction growth. Additional assumptions are described throughout the remainder of this paper.

In this paper we present the following projections:

1. Northern Minnesota pulpwood consumed in pulp production.
2. Pulpwood used in construction board production (particleboard, flakeboard, and hardboard).
3. Fuelwood use.
4. Saw log consumption.

We also summarize projections of fuelwood, pulpwood, and saw log consumption in all uses for the northern Minnesota region, during the period 1980 to 2030, and compare them with current estimates of forest growth in the region. The flowchart in Figure 1 shows the various components of these forecasts.

---

[1] *This study was conducted by the School of Natural Resources, University of Wisconsin, Madison, WI, in cooperation with the USDA Forest Service, North Central Forest Experiment Station, Duluth, MN.*

[2] *In this paper, northern Minnesota is defined by Forest Survey Units 1 and 2. These units are geographic areas used by the USDA Forest Service Resources Evaluation Project to report results of periodic inventories of the Nation's forest resources. Survey Unit 1 includes the counties of Cook, Lake, St. Louis, Carlton, and Koochiching. Survey Unit 2 includes Aitkin, Becker, Beltrami, Cass, Clearwater, Crow Wing, Hubbard, Itasca, Lake of the Woods, Mahnomen, Roseau, and Wadena counties.*

NORTHERN MINNESOTA PULPWOOD CONSUMPTION IN PULP MANUFACTURE

The future consumption of northern Minnesota pulpwood used in pulp production is calculated in four steps:

1. We project pulp production for the entire State of Minnesota.
2. We determine the amount of pulpwood required to produce that amount of pulp.
3. We estimate the species composition of that pulpwood.
4. We project the volume of pulpwood that will originate from northern Minnesota for each species.

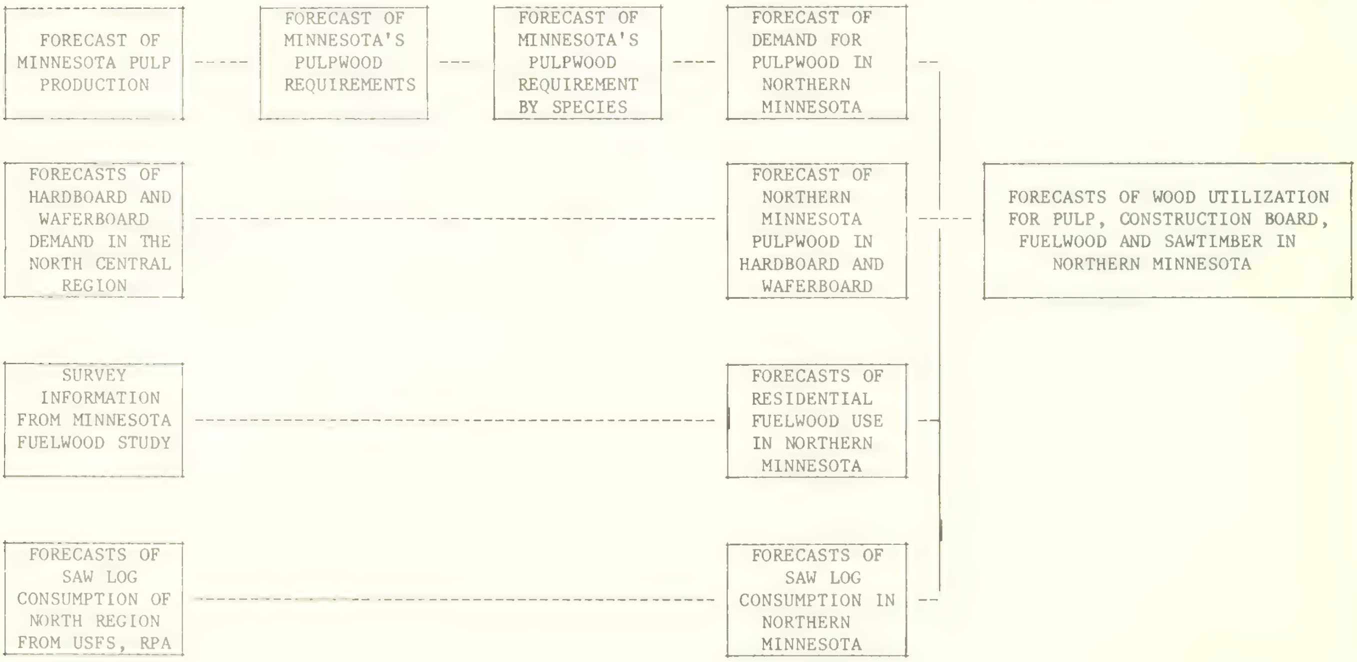
The remainder of this section describes the computations and models used in each step.

Projections of Minnesota Wood Pulp Production

The share of wood pulp produced in Minnesota has remained almost constant during the past decade, relative to production in the entire United States. We assume that this share, which averaged about 1.7 percent between 1967 and 1976 (table 1), will remain the same during the next 50 years. We further assume that national pulp production could develop along the low, medium, and high projections used by the Forest Service in its latest Assessment (USDA Forest Service 1980). These assumptions lead to projections that Minnesota pulp production could increase from about 900 tons in 1980 to 1.3 (low projection) to 1.5 (high projection) million tons by 2000 and to 1.8 (low projection) to 2.9 (high projection) million tons by 2030 (table 2). This is an increase of 44 to 67 percent by 2000 and an increase of 100 to 222 percent by 2030.

Projections of Pulpwood Consumption in Minnesota

As was done in the past, pulpwood requirements have been computed directly from pulp production, assuming that price effects are negligible (Adams 1975, Leuschner 1973). Forest Service data show that


FORECAST OF MINNESOTA PULP PRODUCTION
FORECAST OF MINNESOTA'S PULPWOOD REQUIREMENTS
FORECAST OF MINNESOTA'S PULPWOOD REQUIREMENT BY SPECIES
FORECAST OF DEMAND FOR PULPWOOD IN NORTHERN MINNESOTA
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FORECASTS OF SAW LOG CONSUMPTION IN NORTHERN MINNESOTA

Figure 1.—*Components of wood utilization forecasts for pulp, construction board, fuelwood, and sawtimber in northern Minnesota.*

Table 1.—*Share of Minnesota woodpulp production within total U.S. woodpulp production, 1967-1976*

Year	Minnesota[1]	United States[2]	Minnesota's share
	-----Thousand short tons-----		------Percent------
1967	652.2	36,677	1.8
1968	700.9	40,892	1.7
1969	736.4	42,813	1.7
1970	706.1	43,546	1.6
1971	738.0	43,903	1.7
1972	761.2	46,767	1.6
1973	791.5	48,327	1.6
1974	877.3	48,329	1.8
1975	789.7	43,084	1.8
1976	906.7	47,721	1.9

Average Market Share = 1.7 percent
Standard Deviation = 0.1 percent

[1] U.S. Department of Commerce, Bureau of the Census. Current industrial reports, pulp, paper and board. Series M26A. Washington, DC: U.S. Department of Commerce, Bureau of the Census; various years from 1968 to 1978.

[2] Table XXIV U.S. Production of Woodpulp 1967-1978 in Statistics of Paper and Paperboard, 1979. American Paper Institute 260, Madison Ave., New York (Oct., 1979).

the amount of pulpwood used per ton of pulp has changed little since 1920. The general shift from sulfite and soda to sulfate and semichemical processes, as well as the increasing use of hardwoods, has tended to increase the yield of pulp per cord of wood. Offsetting these trends, however, has been the increasing use in proportions of semibleached and bleached grades of wood pulp requiring more wood per ton of pulp than unbleached grades (USDA Forest Service 1980).

The ratio of cords of pulpwood to tons of pulp produced is estimated from data on pulpwood receipts and pulp production for Minnesota, 1952-1976 (table 3). Based on these data showing a current wood-to-pulp ratio of approximately 1.45 cords per ton and on RPA findings (USDA Forest Service 1980) regarding future technological developments, we assume that pulpwood use per ton of pulp produced will decline from 1.4 cords between 1980 and 1989 to 1.3 cords between 1990 and 2009 and to 1.2 cords between 2010 and 2030.

Table 3.—*Estimates of cords of wood per ton of pulp produced Minnesota*

Year	Minnesota pulp production[1]	Minnesota pulpwood receipts[2]
	Thousand tons	*Thousand cords*
1952	457*	720
1953	475*	662
1954	NA	687
1955	517*	723
1956	550*	835
1957	492*	753
1958	499*	699
1959	641*	813
1960	622	787
1961	654	784
1962	667	828
1963	601	921
1964	674	938
1965	NA	912
1966	701	1063
1967	652	958
1968	701	993
1969	736	1082
1970	706	1058
1971	738	1063
1972	761	1224
1973	791	1223
1974	877	1392
1975	790	1227
1976	907	1178

Cords per ton of pulp
Average 52-61: 753 : 545 = 1.4
Average 62-71: 981 : 686 = 1.4
Average 66-76: 1,133 : 760 = 1.5

[1] From pulp, paper, and board Current industrial Reports. U.S. Department of Commerce, published annually.

[2] From pulpwood production and consumption in the North Central Region. Published annually.

* Calculated as 95% of Regional total.

Table 2.—*Projected pulp production and corresponding pulpwood consumption in Minnesota, 1980-2030*

Year	U.S. pulp production[1]			Minnesota pulp production			Minnesota pulpwood requirements		
	Low projection	Medium projection	High projection	Low projection	Medium projection	High projection	Low projection	Medium projection	High projection
	-----Million tons-----						-----Thousand cords-----		
1980	51.8	52.3	52.8	0.9	0.9	0.9	1,247	1,259	1,271
1985	59.2	61.0	63.0	1.0	1.0	1.0	1,426	1,469	1,517
1990	68.0	71.6	75.7	1.2	1.2	1.3	1,520	1,601	1,693
2000	78.1	85.9	95.0	1.3	1.5	1.5	1,746	1,921	2,124
2010	87.8	100.2	116.5	1.5	1.7	2.0	1,812	2,068	2,404
2020	96.3	115.1	142.0	1.6	2.0	2.4	1,988	2,376	2,931
2030	102.4	128.9	169.1	1.8	2.2	2.9	2,114	2,660	3,490

[1] U.S. Forest Service (1980).

These yield coefficients and the previously computed projections of pulp production lead to projections that Minnesota pulpwood requirements could increase from a range of 1,746 thousand cords (low forecast) to 2,124 thousand cords (high forecast) by 2000 and to 2,114 thousand cords (low forecast) to 3,490 thousand cords (high forecast) by 2030 (table 2). These computations assume that most of the wood used by the Minnesota pulp industry will continue to come from the State (Blyth and Smith 1979).

Projections of Minnesota Pulpwood Consumption by Species

The procedure for dividing total Minnesota pulpwood requirements into three species groups (softwoods, aspen, and other hardwoods) uses two models. One model predicts the softwood and hardwood shares of the total pulpwood requirements. The second model predicts the aspen and other hardwood shares of the total hardwood pulpwood requirements.

Although we assume that pulpwood price will have little influence on total pulpwood use per unit of pulp production, relative prices among species groups will probably influence the species group shares of total pulpwood requirements. There is some flexibility regarding species mix although it is technologically difficult to reduce the amount of fiber used in paper manufacture. Thus, before statistically estimating equations for these two models and testing the price hypothesis, we had to construct price indices for total pulpwood and hardwood pulpwood. The procedure used, based on divisia price indices, is described in the appendix. The price series obtained are reported in the last two columns of table 4.

Two logit models were then developed to predict the effect of price changes on the share of softwoods, aspen, and other hardwoods within total Minnesota pulpwood consumption (see Appendix). These models are used to predict the species share during the next 50 years (1980-2030) (table 5). The softwood share of pulpwood used in Minnesota is projected to decrease from around 40 percent in 1976 to about 25 percent by 2000 and to about 10 percent by 2030. The aspen share of the hardwood pulpwood used in Minnesota is projected to remain about a constant 93 percent throughout the forecast period. The underlying assumptions regarding the future evolution of species group prices are presented in table 6. Specifically, we assume that the real price of softwood pulpwood in Minnesota will grow at the rate projected by the Forest Service for the softwood stumpage equilibrium price in the North Central region. Similiarly, we assume the prices of aspen and other hardwoods will grow at the rate projected by the Forest Service for the hardwood stumpage equilibrium price in the North Central region (USDA Forest Service 1980).

Table 4.—*Prices and quantities of pulpwood delivered to the mill in Minnesota, 1964-1976*
(In 1972 dollars)

	Softwood		Aspen		Other hardwoods		Pulpwood[3]	Hardwood[3] pulpwood
Year	Price[1]	Quantity[2]	Price[1]	Quantity[2]	Price[1]	Quantity[2]	Price	Price
	$/cord	*Thousand cords*	*$/cord*	*Thousand cords*	*$/cord*	*Thousand cords*	*$/cord*	
1964	24.5	562.0	14.1	451.0	13.8	45.5	16.3	14.1
1965	23.3	504.0	17.5	468.0	14.5	41.5	17.6	17.3
1966	25.2	515.0	18.2	612.0	15.6	32.0	18.7	18.1
1967	24.3	536.0	16.8	591.0	13.6	42.0	17.5	16.6
1968	23.0	429.0	17.3	538.0	13.3	23.0	17.3	17.1
1969	23.0	452.0	17.9	660.0	16.1	35.0	18.0	17.7
1970	25.3	483.0	15.6	600.0	15.6	58.0	17.6	15.6
1971	21.3	454.0	14.6	607.0	14.6	65.0	15.7	14.6
1972	22.0	505.0	15.0	689.0	14.0	72.0	16.0	14.9
1973	22.3	518.0	14.9	673.0	14.2	78.0	16.1	14.8
1974	27.8	541.0	14.0	804.0	14.4	80.0	17.3	14.0
1975	24.7	524.0	14.0	615.0	13.2	58.0	16.2	13.9
1976	23.2	422.0	13.8	673.0	12.5	78.0	15.6	13.7

[1] Prices obtained from Lothner, *et al.* 1982. Softwood price is a weighted average of jack pine and spruce prices. Hardwood price is the price of birch.

[2] Quantity data obtained from Blyth and Smith 1979. Softwood quantity consists of pine, spruce, balsam fir, and tamarack. Hardwood quantity consists of birch and other hardwoods.

[3] Pulpwood and hardwood prices constructed using the divisia index methodology (see appendix).

Table 5.—*Actual and predicted pulpwood species shares for Minnesota, 1964-2030*

Year	Softwood		Hardwoods		Aspen		Other Hardwoods	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1964	[1]0.53	[1]0.52	[1]0.47	[1]0.48	[2]0.91	[2]0.91	[2]0.09	[2]0.09
1965	.50	.47	.50	.53	.92	.94	.08	.06
1966	.44	.46	.56	.54	.95	.94	.05	.06
1967	.46	.46	.54	.54	.93	.95	.07	.05
1968	.41	.43	.59	.57	.96	.94	.04	.06
1969	.39	.41	.61	.59	.95	.94	.05	.06
1970	.42	.43	.58	.57	.91	.90	.09	.10
1971	.40	.40	.60	.60	.90	.90	.10	.10
1972	.40	.39	.60	.61	.91	.93	.09	.07
1973	.41	.39	.59	.61	.90	.92	.10	.08
1974	.38	.42	.62	.58	.91	.89	.09	.11
1975	.44	.39	.56	.61	.91	.93	.09	.07
1976	.36	.37	.64	.63	.90	.93	.10	.07
1980		.35		.65		.93		.07
1985		.32		.68		.93		.07
1990		.30		.70		.93		.07
2000		.24		.76		.93		.07
2010		.17		.83		.93		.07
2020		.15		.85		.93		.07
2030		.10		.90		.93		.07

[1] Fraction of total pulpwood use.

[2] Fraction of total hardwood pulpwood use.

Using the species share projections (table 5) and the pulpwood requirement projections (table 2), we determine the future consumption of pulpwood in Minnesota, by species (table 7).

Consumption Projections for Pulpwood Grown in Northern Minnesota

The volume of pulpwood grown in northern Minnesota and used in pulp production has remained a constant share of the volume consumed (and produced) in the entire State. This share has averaged about 0.95, 0.88 and 0.99 for aspen, other hardwoods and softwoods, respectively (table 8), during the 1973-1977 period. We assume these shares will continue at the same level over the projection period.

The projections of pulpwood grown in northern Minnesota used for pulp production are found in table 9. They are obtained by multiplying the species shares (table 8) and the State projections of pulpwood consumed in Minnesota pulp production (table 7).

The medium Forest Service projections imply that total pulpwood use will grow by about 109 percent over the next 50 years, to a total of 2,526 thousand cords, if all our assumptions are valid. The species composition of this volume will change considerably. Hardwoods, which currently account for 65 percent of the volume, will grow to 90 percent. Aspen will continue to make up most of that hardwood share. If we assume that the Forest Service low and high projections correspond to an estimate of the range of possible occurrences, pulpwood requirements from northern Minnesota could vary some 2.0 million to

Table 6.—*Future prices of pulpwood assumed in projections, 1980-2030*

(In 1972 dollars per cord)

Year	Softwood	Aspen	Project price other hardwood	Pulpwood	Hardwood pulpwood
1980	26.3	13.8	12.5	19.0	13.7
1985	30.6	13.8	12.5	20.4	13.7
1990	36.3	13.7	12.4	22.1	13.6
2000	42.6	12.9	11.7	23.2	12.8
2010	50.2	13.7	12.4	25.9	13.6
2020	74.4	15.4	13.9	33.4	15.2
2030	86.9	17.3	15.6	38.3	17.1

Table 7.—*Projections of pulpwood consumed for pulp production in Minnesota, by species, 1980-2030*

(In thousand cords)

	Low projection				Medium projection				High projection			
Year	Total	Softwoods	Aspen	Other hardwoods	Total	Softwoods	Aspen	Other hardwoods	Total	Softwoods	Aspen	Other hardwoods
1980	1,247	436	754	57	1,259	441	761	57	1,271	445	768	58
1985	1,426	456	902	68	1,469	470	929	70	1,517	485	959	72
1990	1,520	456	990	74	1,601	480	1,042	78	1,693	508	1,102	83
2000	1,746	419	1,234	93	1,921	461	1,358	102	2,124	510	1,501	113
2010	1,812	308	1,379	105	2,068	352	1,596	120	2,404	409	1,856	140
2020	1,988	298	1,572	118	2,376	356	1,878	141	2,931	440	2,317	174
2030	2,114	211	1,769	133	2,660	266	2,226	168	3,490	349	2,921	220

Table 8.—*Share of northern Minnesota pulpwood harvest relative to that of the entire State*[1]

	Year						
Species	1973	1974	1975	1976	1977	Mean	S.D.
Aspen	0.965	0.923	0.964	0.963	0.957	0.950	0.017
Other hardwoods	.930	.862	.924	.897	.818	.883	.043
Softwoods	.990	.991	.991	.987	.985	.988	.003

[1] Lake States pulpwood production from roundwood by species, State, and Forest Survey Unit, 1973-1977, (Blyth and Smith 1977).

Table 9.—*Projections of pulpwood grown in northern Minnesota used for pulp production, by species groups, 1980-2030*

(In thousand cords)

	Low projection				Medium projection				High projection			
Year	Total	Softwoods	Aspen	Other hardwoods	Total	Softwoods	Aspen	Other hardwoods	Total	Softwoods	Aspen	Other hardwoods
1980	1,197	431	716	50	1,209	435	723	51	1,220	440	730	51
1985	1,367	451	857	60	1,409	464	883	62	1,455	480	911	64
1990	1,456	451	940	66	1,534	475	990	69	1,622	502	1,047	73
2000	1,668	414	1,172	82	1,836	455	1,290	90	2,030	504	1,426	100
2010	1,726	304	1,329	93	1,970	342	1,516	106	2,290	404	1,763	123
2020	1,892	295	1,493	104	2,261	352	1,784	125	2,789	434	2,201	154
2030	2,007	209	1,681	118	2,526	263	2,115	148	3,314	345	2,775	194

3.3 million cords (table 10). Nevertheless, even the lowest projection will mean a 71-percent increase in demand.

NORTHERN MINNESOTA PULPWOOD CONSUMPTION IN CONSTRUCTION BOARD PRODUCTION

Recently, two new waferboard mills were built in Bemidji and an existing waferboard plant in Grand Rapids doubled its production. A fourth waferboard plant has been completed in Cook, but awaits start-up.

The primary market opportunities for these building products are in new residential construction (Dickerhoof and Marcin 1978). The demand for waferboard and particleboard is partly a function of how much they can be substituted for other construction materials. To determine the amount of northern Minnesota pulpwood that will be used in manufacturing these products, we first project the demand for the end products. This, in turn, leads to estimates of raw material requirements.

Market Area

We assume that the primary market area for waferboard and particleboard products from northern

Table 10.—*Projections of prices and housing starts used in estimating future consumption of construction board products in the North Central Region*

Year	Price indices (1967 = 100)					Housing starts[1]	
	P_S	P_L	P_R	P_M	P_W	High projection	Low projection
						-----Thousand units-----	
1980	140	128	100	132	233	432	399
1985	167	157	123	158	278	431	384
1990	202	194	152	191	336	385	336
2000	228	202	158	215	378	341	279
2010	252	214	167	238	418	413	333
2020	274	222	173	259	455	369	294
2030	299	232	181	283	496	370	294

[1]P_S = wholesale price indices of Douglas-fir softwood lumber (1967 = 100)
P_L = wholesale price indices of plywood (1967 = 100)
P_R = wholesale price indices of hardboard and waferboard (1967 = 100)
P_M = wholesale price indices of other construction materials (1967 = 100)
P_W = index of wages in construction (1967 = 100)
Source: Marcin, T. (1977).

Minnesota will be the North Central area (Dickerhoof and Marcin 1978). The North Central region encompasses 11 States including the Chicago market (Adams and Haynes 1980). Because waferboard is heavier than plywood of the same thickness (Koch 1978), we can expect that increasing transportation costs may limit the market area for waferboard and particleboard produced in northern Minnesota to the North Central region.

Because many of the mills in northern Minnesota are just beginning production, it is difficult to determine their market share (Carpenter 1980). The model described in the next section explicitly accounts for substituting the new waferboard products for plywood and softwood lumber. Whether waferboard manufactured elsewhere will compete in the North Central region remains an unanswered question. The most likely source of future competition will probably come from Canadian waferboard mills (Guss 1979). Because of the uncertainty of future developments, we assume that the market share for northern Minnesota mills will remain constant so that the supply of waferboard from these mills will grow in direct proportion to the demand from the entire North Central region.

Projections of Hardboard and Waferboard Consumption in the North Central Region

The demand for hardboard and waferboard is based on the estimated derived demand equation for hardboard and particleboard described in Rockel and Buongiorno (1982). Using duality theory, we obtained a derived demand function for hardboard and particleboard, consistent with a statistically determined cost function for residential construction. In the resulting model the quantity of hardboard and particleboard demanded is a function of the prices of softwood lumber, plywood, hardboard and particleboard, other materials, and labor, as well as the number of residential housing starts, and a time trend. The equation takes into account the price elasticity of hardboard and particleboard as well as the cross price elasticities of substitution with other inputs. This is of particular importance with respect to waferboard because it competes in price and function with CDX softwood plywood (Koch 1978). The empirical equation used to forecast hardboard and waferboard demand is (Rockel and Buongiorno 1982).

$$\begin{aligned}\triangle D/D = {} & \underset{(0.02)^{**}}{0.09}\ \triangle P_S/P_S + \underset{(0.02)^{**}}{0.05}\ \triangle P_L/P_L - \underset{(0.03)^{**}}{0.95}\ \triangle P_R/P_R \\ & + \underset{(0.03)^{**}}{0.12}\ \triangle P_M/P_M + \underset{(0.02)^{**}}{0.68}\ \triangle P_W/P_W \quad (1) \\ & + \underset{(0.005)^{**}}{0.982}\ \triangle Q/Q + \underset{(0.0015)^{**}}{0.0108}\end{aligned}$$

where $\triangle D/D$ is the yearly relative change in the quantity of hardboard and waferboard demanded in the North Central region, $\triangle P_S/P_S$, $\triangle P_L/P_L$, $\triangle P_R/P_R$, $\triangle P_M/P_M$, $\triangle P_W/P_W$ are the yearly relative changes in prices of softwood lumber, plywood, hardboard and waferboard, other materials, and labor, respectively. $\triangle Q/Q$ is the yearly relative change of residential housing units in the North Central region. The numbers in parentheses are standard errors. ** indicates a coefficient significantly different from zero at the 0.99 confidence level.

Projections of demand using equation (1) require projections of the independent variables. We assumed that the price of other materials (P_M), labor (P_W) and lumber (P_X) would grow as fast as the price for softwood lumber. Similarly, waferboard prices (P_R) and plywood prices (P_L) would grow as fast as pulpwood price during the next 50 years (USDA Forest Service, 1980).

Projections of residential housing starts in the North Central region were obtained from Marcin (1977). Two sets of housing projections, high and low, were used (table 10).

Construction board consumption forecasts in the North Central region are obtained by applying the independent variable assumptions for the prices of softwood lumber (P_S), plywood (P_L), waferboard (P_R), other materials (P_M), and labor (P_W) (table 10) to equation (1). With these assumptions, the model projects that construction board consumption will increase in a range of 1,209 MMSF (low projection) to 1,516 MMSF (high projection) by 2030. This is a 45- percent (low projection) to 70-percent (high projection) increase over the next 50 years (table 11). Forest Service assessment projections (USDA Forest Service 1980) are also reported for comparison. The Forest Service assessment report predicts a faster rate of growth in the early years, but lower levels by the end of the projection period. Our low projection of consumption for board is near the high Forest Service assessment projections (table 11). The broad range of projections underlines the high uncertainty faced in doing such long-term projections. The projections in this report are closely tied to housing forecasts, as are the projections in the assessment report. However, even as housing starts decline after the year 2010 (table 10), consumption of board products still increases due to the substitution of these products for more expensive ones, notably lumber and plywood. Our projection accuracy, therefore, depends on the validity of our future price assumptions and the accuracy of our elasticity of substitution estimates.

Table 11.—*Projections of construction board consumption in the North Central region (1980-2030)*
(In million square feet, ½″)

Year	This report[1]		Forest Service[2]	
	High projection	Low projection	High projection	Low projection
1980	898	830	816	754
1985	918	819	929	828
1990	848	742	963	840
2000	901	740	994	813
2010	1,260	1,020	1,249	1,007
2020	1,308	1,047	1,200	956
2030	1,516	1,209	1,231	978

[1] Includes hardboard and particleboard (including waferboard, flakeboard, composite board, and medium density fiberboard).

[2] Includes hardboard, insulating board, and particleboard (including waferboard, flakeboard, composite board, and medium density fiberboard) (U.S. Forest Service 1980).

Projections of Northern Minnesota Pulpwood Used in Hardboard and Waferboard Manufacture

Our projections are made using projections for the entire North Central region and assuming the northern Minnesota mills will maintain a constant 57-percent share of the market. We assume timber requirements will originate from these same northern Minnesota counties. We further assume that 1.16 cords of wood will be required per thousand square feet of 1/2 inch board (Harpole 1978). No attempt is made to distinguish the raw material by species but we expect that most of it will be aspen (Carpenter 1978). In our analysis we assume construction board production will increase to a range of 686 thousand cords (low forecast) to 860 thousand cords (high forecast) by the year 2030 (table 12).

FUELWOOD CONSUMPTION IN NORTHERN MINNESOTA

The energy crisis and the related increase in the price of heating fuels since 1973 have increased the interest in using fuelwood for residential heating and for energy. A survey carried out during the 1979-1980 heating season (Minnesota DNR 1981) indi-

Table 12.—*Projections of Northern Minnesota aspen pulpwood used for construction board production, 1980-2030*
(In thousand cords)

Year	High projection	Low projection
1980	509	971
1985	521	465
1990	482	421
2000	511	420
2010	715	579
2020	742	594
2030	860	686

cates that 33 percent of Minnesota households used some amount of fuelwood during the 1978-1979 winter season. In northern Minnesota, about 45 percent of households did so. In addition, many of the pulp and paper mills in the region use wood chips and residues to fire their boilers. It is estimated that the pulp, paper, and paperboard industry obtained 47 percent of its energy from waste fuels in 1980 (Pulp and Paper 1981). However, not all residues and wastes generated in production are yet being used. Any increase in the use of wood as an energy source within the industry will probably arise from better utilization of wood already being harvested rather than from additional harvest. The consumption of wood for fuel by the pulp industries has already been accounted for in estimating northern Minnesota pulpwood requirements for pulp production. Consequently, we only develop projections of residential fuelwood consumption.

Our projections rely heavily on the 1979-1980 Minnesota Department of Natural Resources fuelwood utilization survey, described below.

The 1979-1980 Minnesota Fuelwood Utilization Survey

The Minnesota Department of Natural Resources conducted a survey of fuelwood use during the heating season 1979-1980 in all Minnesota forest survey units. Respondents were classified into households that burn wood as:

(a) A major source of heat,
(b) A secondary source of heat,
(c) Mostly for aesthetic considerations.

The survey also estimated the amount of fuelwood used by each category of user. In survey unit 1 (aspen-birch) about 45 percent of all households used fuelwood in some manner and 21 percent of households were major users. In survey unit 2 (northern pine) 54 percent of all households used fuelwood and 37 percent of households used it as a major source of fuel. Total use of fuelwood averaged 2.1 and 3.2 cords per household in survey units 1 and 2, respectively. The 1979-1980 survey showed the species distribution for the entire State only, but specific data for survey units 1 and 2 were available from a previous survey (Minnesota Department of Natural Resources 1980). Hardwoods represented about 72 percent of all fuelwood use, aspen represented about 23 percent, and softwoods represented 5 percent. The major survey data used in our projections are presented in table 13.

Table 13.—*Summary of findings of the 1979-1980 Minnesota Department of Natural Resources fuelwood consumption survey used to project fuelwood consumption in northern Minnesota (Minnesota DNR 1981.)*

	Survey units	Type of use			
		Major	Secondary	Pleasure	Total
Households using fuelwood (percent)	1	21	15	9	45
	2	37	12	5	54
Wood use (standard 4′ x 4′ x 8′ cds/household/yr)	1	6.8	3.2	1.6	2.1
	2	7.1	3.7	1.9	3.2
		Hardwoods	Aspen	Softwoods	
Species used[1] (percent)	1	72	24	4	
	2	71	23	6	

[1] Data on species noted are from Minnesota DNR (1980).

Projections of Residential Fuelwood Use in Northern Minnesota

Our projections assume that the pattern of wood burning will not differ significantly from that determined by the 1979-1980 Minnesota Department of Natural Resources survey described above. The only source of growth will be the increase in the number of households in the region. Therefore, resulting estimates could be conservative because they ignore further increases in fossil fuel prices. On the other hand, the statewide fuelwood survey has shown that the percentage of households that burn wood, especially for heating, is closely related to wood availability (Minnesota Department of Natural Resources 1980). The projected increase in wood for industrial uses will limit the wood supply and increase either the market or the procurement cost of timber, including fuelwood. To accurately project what will happen to fuelwood prices and their effect on fuelwood utilization is difficult. We make the simple assumption that the two sets of forces just described will to some extent compensate each other.

The future number of households in northern Minnesota is predicted by assuming the same growth rates of household formation predicted by Marcin for the North Central region (Marcin 1977) and used by the Forest Service for the latest timber assessment

Table 14.—*Projections of households in northern Minnesota, 1980-2030*[1]
(In thousand units)

	Total		Survey Unit 1		Survey Unit 2	
Year	High projection	Low projection	High projection	Low projection	High projection	Low projection
1980	187	187	104	104	83	83
1985	200	198	111	110	89	88
1990	211	207	117	115	94	92
2000	224	218	124	121	100	97
2010	240	229	133	127	107	102
2020	251	240	139	133	112	107
2030	268	253	148	139	120	114

[1] Projections based on Minnesota DNR base year population (Minnesota DNR 1981) and household formation growth rates for the North Central Region (Marcin 1977).

(USDA Forest Service 1980). High and low forecasts were obtained, using Forest Service assumptions. The Minnesota Department of Natural Resources fuelwood survey data population projections are made for the two survey units in northern Minnesota (table 14).

Based on the household formation forecasts and the fuelwood utilization data, we project residential fuelwood use (table 15). The high projection shows a 43-percent increase in fuelwood use over the next 50 years; the low projection is only slightly lower. The major part of the residential fuelwood volume is hardwood. Aspen represents about 24 percent of the hardwoods total volume.

PROJECTIONS OF CONSUMPTION OF SAW LOGS GROWN IN NORTHERN MINNESOTA

To give a complete picture of the future consumption of all timber grown in northern Minnesota, we project the consumption of sawtimber (also equal to removals, or production). We stress, however, that the results are only indications.

Softwood saw log output in the State of Minnesota declined from 1960 to 1975, while hardwood saw log output increased slightly (table 16). However, the rates of growth vary greatly depending on which years are used as reference. We compare these trends with the growth of saw log production in the entire Northern Region (USDA Forest Service 1980). During 1952 to 1976, softwood saw log production grew very little in the Northern Region, while hardwood saw log production grew at an annual rate of between 1 and 2 percent (table 17). Because only limited data are available, it is not possible to establish any testable relation between removals in Minnesota and the Northern Region, let alone between northern Minnesota and the Northern Region.

Therefore, we make the simple assumption that saw log removals in Minnesota, for both hardwoods and softwoods, will grow at the same rate as in the entire Northern Region. In addition, we assume that the share of removals from northern Minnesota, relative to all Minnesota, will remain constant. These shares were recently estimated as 98 percent for softwoods and 66 percent for hardwoods (Blyth *et al.* 1980). Our projections indicate that softwood saw log production will increase from 128 thousand cords in

Table 15.—*Projections of residential fuelwood in Northern Minnesota, by major species group, 1980-2030*
(In thousand cords)

	Residential fuelwood consumed							
	Total		Softwood		Aspen		Other hardwoods	
Year	High projection	Low projection	High projection	Low projection	High projection	Low projection	High projection	Low projection
1980	484	484	24	24	114	114	346	346
1985	516	512	26	26	122	120	369	366
1990	545	535	27	27	128	126	390	383
2000	579	563	29	28	136	132	414	403
2010	620	592	31	30	146	139	443	423
2020	649	621	32	31	153	146	464	444
2030	693	654	35	33	163	154	496	468

Table 16.—*Saw log production in Minnesota, 1960-1975*[1]

Year		1960	1973	1975
		-Million board feet, Intl. ¼" log rule-		
Softwoods		76.1	55.2	60.9
Hardwoods		92.0	122.3	95.2
		-Percent per year-		
Rates of	1960-1973	−2.4		
Growth of Softwoods	1960-1973	−2.4		
Rates of	1960-1973	2.2		
Growth of Hardwoods	1960-1975	0.2		

[1] Blyth *et al.* (1980), Blyth and Smith (1979).

Table 17.—*Saw log production in the Northern Region*[1]*, 1952-2030*

Year		1952	1962	1970	1976
		Million board feet, Int. ¼" log rule			
Softwoods		1,624	1,271	1,784	1,928
Hardwoods		3,729	3,998	5,298	4,996
		-Percent per year-			
Rates of	1952-1970: 0.5				
Growth of Softwood	1952-1976: 0.7				
Rates of	1952-1970: 2.0				
Growth of Hardwood	1952-1976: 1.2				

[1] USDA Forest Service Northeast, North, and North-Central Regions (USDA Forest Service 1980).

1980 to 196 thousand cords in 2030 in northern Minnesota, an increase of 53 percent (table 18). Hardwood saw log production in northern Minnesota is projected to rise from 127 thousand cords in 1980 to 207 thousand cords in 2030, a 63-percent increase. To determine the aspen share of all hardwood production in northern Minnesota, we assume that 74 percent of hardwood removals will be aspen, as observed in Jakes and Raile (1980) and Spencer and Ostrom (1979).

PROJECTIONS OF CONSUMPTION OF TIMBER GROWN FOR PULP, CONSTRUCTION BOARD, FUELFOOD, AND LUMBER

The aggregate projections of consumption of pulpwood, fuelwood, and saw logs produced from northern Minnesota forests are reported in table 19. They were obtained by adding the corresponding entries from table 7 (consumption for pulp production), table 12 (consumption for manufacture of construction board), table 15 (consumption for fuelwood), and table 18 (consumption for saw logs). Only low and high projections are presented because intermediate projections consistent with Forest Service assumptions in the Analysis of the Timber Situation in the United States could be obtained only for pulpwood used in pulp manufacture.

Table 18.—*Estimates of past saw log production and projections for the Northern Region, Minnesota and northern Minnesota for selected years*

	1960	1975	1980	1985	1990	2000	2010	2020	2030
	Million board feet intl. ¼" log rule								
Northern Region[1]									
Softwoods	1,296	1,902	1,947	1,972	1,997	2,271	2,512	2,747	2,976
Hardwoods	3,972	5,044	4,863	4,702	4,548	5,403	6,272	7,222	7,932
Minnesota[2]									
Softwoods	76.1	60.9	62.4	63.2	64.0	72.7	80.3	87.8	95.1
Hardwoods	92.0	95.2	91.8	88.7	85.8	101.8	118.0	135.8	149.1
Northern Minnesota[3]									
Softwoods	74.1	59.8	61.1	61.9	62.7	71.2	78.7	86.1	93.2
Hardwoods	48.7	62.5	60.6	58.6	56.6	67.2	77.9	89.6	98.4
	Thousand cords								
Softwoods	156	126	128	130	132	150	165	181	196
Hardwoods	102	131	127	123	119	141	164	188	207
Aspen[3]	75	97	94	91	88	104	121	139	153
Other hardwoods	27	34	33	41	31	37	43	49	54

[1] Data for 1960 and 1975 estimated from data in Table 17; data for 1980 to 2030 obtained from the Analysis of the Timber Situation in the United States (U.S. Forest Service 1980).

[2] Data for 1960 estimated from published and unpublished data from 1960 survey, data for 1975 from Blyth *et al.* (1980).

[3] Assuming the same species shares as in 1977 (Jakes and Raile l980, Spencer and Ostrom 1979).

Table 19. —*Summary projections of consumption of timber grown in northern Minnesota for pulp, construction board, fuelwood, and sawtimber, by species, 1980-2030*

(In thousand cords)

Year	Wood utilization							
	Low projection				High projection			
	Total	Softwoods	Aspen	Hardwoods	Total	Softwoods	Aspen	Hardwoods
1980	1,957	588	933	436	2,519	547	1,485	437
1985	2,665	612	1,578	475	2,816	641	1,693	482
1990	2,728	615	1,625	488	2,971	667	1,800	504
2000	3,020	597	1,890	533	3,505	689	2,252	564
2010	3,292	503	2,218	571	4,069	605	2,838	626
2020	3,572	510	2,451	611	4,691	653	3,351	687
2030	3,857	440	2,762	655	5,447	580	4,097	770

The aggregate projections indicate that total consumption of northern Minnesota pulpwood, fuelwood, and saw logs will grow between 97 percent (low forecast) and 116 percent (high forecast) over the 1980-to-2030 period, leading to final consumption of 3,851 to 5,449 thousand cords in 2030, depending on the set of assumptions made. The range between the two projections underline the great uncertainty surrounding these projections.

These aggregate projections of consumption can be compared with preliminary estimates of current growth. The net annual growth of growing stock for northern Minnesota (Survey Units 1 and 2) is currently about 3,400 thousand cords per year, for all species. This is slightly below the low projection for the year 2030 in table 19. The net growth of aspen is approximately 1,600 thousand cords per year—much below the low projection of consumption in table 19. Some other species must be substituted for aspen if even the low projection in table 19 is to be met. Nevertheless, it seems that the low projection can be achieved assuming a minimum level of management and an active program of substituting other species for aspen. On the other hand, the high projection would require a large investment in forest management to increase productivity in northern Minnesota, especially for aspen.

We emphasize that this analysis represents a simple, straightforward approach to the problem of assessing consumption of timber produced in a small area like northern Minnnesota. As more comprehensive data on timber supply and consumption patterns become available, these projections will be revised.

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APPENDIX

Divisia Price Indices for Pulpwood

We chose to construct divisia indices of the pulpwood price for use in the share equations. The pulpwood divisia indices are based upon the theoretical concept that producers minimize costs of production by using various species in proportions so that their marginal productivities are equal to their purchase prices. These indices can be interpreted as using marginal productivities to weight prices (Hulten 1973). The divisia index is consistent with the translog production function (Christensen *et al.* 1973) used here (Christensen 1975). The specific form of the function is

$$ln\ P = \sum_{i=1}^{n} \alpha_i\ ln\ P_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij}\ ln\ P_i\ ln\ P_j + \epsilon_t \tag{A1}$$

where P is the price index for the group of species under consideration, P_i is the price of species i, n is the number of species in the group. ϵ_t is a random residual.

The constants α and γ relate to characteristics of the underlying cost and dual production function. Homogeneity of costs of degree one in prices impose that (Berndt and Christensen 1973):

$$\sum_{i=1}^{n} \alpha_i = 1, \quad \sum_{i=1}^{n} \gamma_{ij} = \sum_{j=1}^{n} \gamma_{ij} = 0$$

Logarithmic differentiation of (1) and application of Shephard's lemma (Diewert 1974) lead to the share equations:

$$M_i = \alpha_i + \sum_{j} \gamma_{ij}\ ln\ P_i + \epsilon_{it}\quad i = 1,\ldots,n \tag{A2}$$

where M_i is the value share of species i relative to the value of total pulpwood use in Minnesota.

Data on pulpwood production in Minnesota, by species, for the period 1964 to 1976 were obtained from Blyth *et al.* (1980) and from Blyth and Smith (1979). Prices of pulpwood delivered to the mill were obtained from Lothner *et al.* (1982). Prices were deflated by the GNP price deflator (U.S. Department of Commerce 1980) to given prices in 1972 dollars.

Using the data reported in table 4, we estimated the share equations (A2) simultaneously using Zellner's (1962) efficient estimation procedure. The following price equations were obtained:

$$\begin{aligned} P_p = {} & \underset{(0.22)}{0.39}\ P_a + \underset{(0.23)^{*}}{0.43}\ P_s + \underset{(0.03)^{**}}{0.13}\ P_b + \underset{(0.014)}{0.001}\ P_a P_b \\ & + \underset{(0.0006)^{**}}{0.02}\ P_a^2 - \underset{(0.01)^{**}}{0.02}\ P_a P_s\ \ .01\ P_s P_b + \underset{(0.01)}{0.01}\ P_s^2 \\ & + \underset{(0.007)}{0.004}\ P_b^2 \end{aligned} \tag{A3}$$

$$\begin{aligned} P_h - {} & \underset{(0.006)^{**}}{0.91}\ P_a + \underset{(0.006)^{**}}{0.09}\ P_b + \underset{(0.05)^{**}}{0.22}\ P_a^2 + \underset{(0.05)^{**}}{0.22}\ P_b^2 \\ & \underset{(0.05)^{**}}{0.44}\ P_a P_b \end{aligned} \tag{A4}$$

Where p_p and P_h are the divisia prices of total pulpwood and hardwood, respectively. P_a and P_s are the prices of aspen and softwood; P_b is the price of birch used as an indicator of the price of other hardwoods. The numbers in parenthesis are standard errors. * and ** indicate coefficients significantly different from zero at the 0.95 and 0.99 confidence interval, respectively. The price series obtained by applying equations (A3) and (A4) are reported in the last two columns of table 4.

Models of Pulpwood Species Shares

We developed two models for allocating total Minnesota pulpwood consumption to species groups (softwoods, aspen, and other hardwoods). The first model develops a relation for dividing total Minnesota pulpwood consumption into the softwood and hardwood pulpwood shares and follows the logistic law:

$$\begin{aligned} S_{st} &= Q_{st}/Q_{pt} - 1/(1 + \exp.\ (\beta_0 + \beta_1 \frac{P_s}{P_p} + \beta_2\, t + \epsilon \\ S_{nt} &= 1 - S_{st,}\ 0 \leqslant S_{st} \leqslant 1,\ 0 \leqslant S_{ht} \leqslant 1, \text{ and } Q_{pt} \\ &= Q_{st} + Q_{ht} \end{aligned} \tag{A5}$$

where:

S_{st} = relative share of softwood pulpwood in year t

S_{ht} = relative share of hardwood pulpwood in year t

Q_{pt} = total volume of pulpwood consumed in year t

Q_{st} = volume of softwood pulpwood consumed in year t

Q_{ht} = volume of hardwood pulpwood consumed in year t
P_s = the price of softwood pulpwood
P_p = the price of all pulpwood determined in the previous section by the divisia index method
t = time, a proxy variable for technological change
ϵ_t = random residual
$\beta_0, \beta_1, \beta_2$ = constant coefficients

The relation for dividing total hardwood pulpwood requirements into the aspen and other hardwood pulpwood shares follows a similar logistic law:

(A6)

$$S_{st} - Q_{at}/Q_{ht} = 1/(1 + \exp. (\beta_0 + \beta_1 \frac{P_a}{P_h} + \beta_2 t + \epsilon_t)$$

$$S_{ot} = 1 - S_{at}' \; 0 \leq S_{at} \leq 1, \; 0 \leq S_{ot} \leq 1, \text{ and } Q_{ht} = Q_{at} + Q_{ot}$$

where:

S_{at} = relative share of aspen pulpwood in year t
S_{ot} = relative share of other hardwood pulpwood in year t
Q_{at} = volume of aspen pulpwood consumed in year t
Q_{ot} = volume of other hardwood pulpwood consumed in year t
P_a = price of aspen pulpwood
P_h = the price of hardwood pulpwood determined in the previous section by the divisia index

Q_{nt}, t, β_0, β_1, and β_2 are defined above.

The logit models (A5) and (A6) have attractive properties for analyzing interspecies competition. For example, in equation (A5) one would expect the coefficient β_1 to be positive so that if the price of softwood pulpwood decreases relative to hardwood pulpwood, the share of softwood pulpwood used in pulp production increases towards a maximum of unity or 100 percent. However, as the share of softwood pulpwood increases, greater relative price changes are needed to induce a marginal change in the softwood pulpwood share. Symmetrically, as the relative price of softwood pulpwood increases, the softwood pulpwood share declines asymptotically towards zero.

The logit models can be easily linearized for estimation. For example, model (A5) can be written:

(A5)

$$ln\ (Q_{pt}/Q_{st} - 1) = \beta_0 + \beta_1 \frac{P_s}{P_p} + \beta_2 t + \epsilon_t$$

However, the variance of the residuals is not constant. To correct for heteroscedasticity, generalized least squares estimates can be obtained by weighting all observations by the quantity (DeGroot 1976):

$w_t = (Q_{st} (Q_{pt} - Q_{st})/(Q_{pt} - 1))^{1/2}$ where w_t is the weight of the observations in year t and the other terms were defined above.

The estimation results using models (A5) and (A6) appear in table 20. The price coefficients (β_1) have the expected positive sign and are highly significant. Therefore, in equation (A5) as the price of softwood pulpwood increases relative to hardwood pulpwood, the softwood pulpwood share declines asymptotically towards zero. In equation (A6) as the relative price of aspen pulpwood to other hardwood pulpwood decreases, the share of aspen pulpwood increases towards unity or 100 percent. The time trend coefficient (β_2) was negative and significant in the softwood share equation (A5) indicating that technological change has led to a decrease in the softwood pulpwood share. The time trend did not play a significant role in the aspen share equation (A6) and was, therefore, omitted from the final model.

As indicated by the coefficients of determination, and by a comparison of actual against predicted values during the sample period (table 5), the logit models explain well the changes in the species composition of pulpwood used in Minnesota.

Table 20.—*Estimated logit models of softwood and aspen shares of pulpwood consumed in Minnesota, 1964-1976*

Parameters	Share of softwood relative to all pulpwood	Share of aspen relative to hardwood pulpwood
0	−1.16	−57.6
	(0.49)**	(21.3)**
1	0.86	59.8
	(0.36)**	(21.1)**
2	−0.05	—
	(0.01)**	
N	13	13
SSR	0.0004	0.024
R^2	.76	.88

** indicate coefficients significantly different from zero at the 99 percent confidence level.

N = number of observations, SSR = sum of squared residuals, R^2 = coefficient of determination.

Rockel, Mark; Buongiorno, Joseph; Lothner, David C.; Kallio, Edwin.
Future consumption of timber grown in northern Minnesota: 1980-2030. Res. Pap. NC-244. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 15 p.

Consumption projections are reported by major species groups in northern Minnesota for pulpwood used in pulp production and in construction board, fuelwood, and sawtimber from 1980 to 2030. Total consumption of pulpwood could grow between 97 percent and 116 percent.

KEY WORDS: Pulpwood, fuelwood, sawtimber, divisia indices, aspen, other hardwoods, logit models, softwood.

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Above-ground Weights for Tamarack in Northeastern Minnesota

Eugene M. Carpenter

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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ABOVE-GROUND WEIGHTS FOR TAMARACK IN NORTHEASTERN MINNESOTA

Eugene M. Carpenter, *Market Analyst,*
Duluth, Minnesota

Timber supplies can be extended by using the tree species and more of the residue usually bypassed in harvesting. Opportunities for utilizing these materials have been enhanced by whole-tree chippers that allow the in-woods processing of the entire above-ground portion of a tree into an easily transportable product—chips.

A convenient method of estimating the amount of material in the above-ground portion of trees before harvesting is the use of weight prediction equations. From these equations we can also evaluate the yield potential, by tree component, of the entire renewable forest resource.

To promote the use of these materials, it is helpful to have information about specific gravity and seasonal moisture content by tree components. By determining the wood-bark ratio, we can judge the magnitude of the problem firms may face where processes can tolerate only a limited amount of barky chips. The intent of our study was to provide this useful information for tamarack.

PROCEDURE

Field

A stratified random sample of 53 trees was selected within four representative natural tamarack stands in the Superior National Forest in northeastern Minnesota (table 1). The distribution of sample trees over the d.b.h. range was approximately proportional to the distribution of tamarack trees in the Lake Superior Forest Survey Unit (Anonymous 1964).

Sample trees were felled leaving a 6-inch stump. Total height was measured after felling; the bole was severed at 2 inches diameter outside bark (d.o.b.) and stem length was measured. All live branches including foliage and all dead branches were cut off flush with the bole and weighed. The stem portion above 2 inches d.o.b. was included with the branches. Two 4-foot bolts were cut from the butt end, and the remaining bole was then cut into 8-foot bolts, usually ending with a random length piece at the top. Each bolt was weighed to the nearest pound in a sling attached to a crane scale that had been carefully calibrated.

For all sample trees, a 1-inch-thick disk was cut from the butt end of each bolt and from the top of the last piece. These disks were measured for d.o.b., diameter inside bark (d.i.b.), and heartwood diameter to the nearest 0.01 inch. The disks were quartered and one wedge was separated into bark, sapwood, and heartwood components. Each component was weighed immediately to the nearest 0.1 gram on a triple-beam balance and bagged for transport to the laboratory. The remaining portions of each disk were bagged and also taken to the laboratory.

Additional trees were felled near the middle of each month to determine seasonal moisture content, and with the original 53 trees, were used to determine average specific gravity of bark, sapwood, and heartwood proportions including variations based on height above stump. The bole and branch material from these additional trees was not weighed.

Laboratory

Total bolt volume, wood volume, and heartwood volume were calculated by Smalian's formula.[1] Bark and sapwood volumes were determined by subtraction. The bolt weights were combined to determine the green weight of the stem to a 2-inch d.o.b., and with the branches, the weight of the total tree.

---

[1] *Smalian's formula: Volume* $= \frac{A + a}{2} L$ *where A is area at the large end, a is area at the small end, L is length.*

Table 1.—*Means and ranges of selected variables of sample tamarack trees by d.b.h. class*

D.b.h. (inches)	Trees	D.b.h.		Total height		Stem length[2]		Ave.[3]	
		Ave.[1]	Range	Ave.	Range	Ave.	Range	Ave.	Range
	Number	-----*Inches*-----		--------------*Feet*--------------				----*Years*----	
3	3	3.1	3.0-3.2	25	20-31	14	11-18	39	33-49
4	7	3.9	3.5-4.3	33	25-49	22	13-38	49	30-85
5	12	5.0	4.5-5.4	39	33-50	28	23.36	45	32-62
6	10	5.9	5.5-6.3	42	33-51	31	25-40	55	44-91
7	6	6.9	6.6-7.4	48	43-56	39	33-45	50	43-56
8	2	7.8	7.6-8.0	53	52-54	41	41-43	54	53-55
9	3	8.7	8.5-9.0	58	57-59	48	48	52	46-62
10	3	9.9	9.5-10.2	52	48-56	42	36-48	54	44-71
11	3	11.1	10.8-11.4	58	52-63	48	43-53	65	56-82
12	2	11.8	11.6-11.9	64	60-69	55	50-60	55	53-57
13	1	12.8	—	70	—	63	—	70	—
14		13.7	—	66	—	59	—	71	—

[1] Quadratic mean diameter.
[2] Stem length from a 6-inch stump to 2 inches d.o.b.
[3] Age at d.b.h.

Ovendry moisture content was determined by drying the component samples at 104° C until constant weight was reached.

$$\text{Wood or bark moisture content} = \frac{\text{green weight} - \text{ovendry weight}}{\text{ovendry weight}}$$

The average moisture content for each bolt component was determined by weighting the component moisture content at each end of the bolt by a factor related to its disk basal area. These factors were derived as follows:

For total	DOB^2
For wood	DIB^2
For heartwood	$(\text{heartwood diameter})^2$
For sapwood	$DIB^2-(\text{heartwood diameter})^2$
For bark	DOB^2-DIB^2

The weighted average moisture content of each component for the total tree was calculated using component volumes in each bolt as weighting factors. The dry weight of the tree was determined by applying the average weighted bolt moisture content to the bolt green weight and summing bolt dry weights to arrive at total stem dry weight. We then added the dry weight of the top and limbs, which was determined from moisture samples taken from the live and dead branches.

From the unused portion of each disk, an additional 2-inch wedge was cut for the gravimetric determination of specific gravity by water displacement. The TAPPI standard method was used to determine the specimen volume (TAPPI 1953).

Specific gravity was determined for each component by dividing ovendry weight by green volume.

$$\text{Specific gravity} = \frac{\text{ovendry wood (bark) weight (gm)}}{\text{green wood (bark) volume (cc)}}$$

Average component specific gravity for a d.b.h. class and height point was determined by weighting the specific gravity of each disk component, as in determining moisture content.

Average green stem density was determined by dividing the total stem green weight by the Smalian stem volume; it was then converted to dry density using average stem moisture content.

For each d.b.h. class, the percents of bark, sapwood, and heartwood by green weight and height in tree were calculated using the green weight of the component moisture content samples. Each individual component weight was weighted by disk d.o.b.^{2}, and the average was determined by summing the component weighted values and dividing by the total weighted value of the component for all trees at each height point in the d.b.h. class.

To estimate stem weight to a 4-inch d.o.b., we had to proportion the bolts arbitrarily because the stem wasn't cut at this point. For bolts severed within one-tenth of an inch of 4 inches d.o.b., data were used without adjustment. For other bolts, the end d.o.b.'s of the bolt containing the 4-inch diameter were used to proportion the 8-foot length as a linear function of taper and to calculate the length of bolt from 4 inches d.o.b. to the small end diameter. Using this length and these diameters, we calculated a volume for this bolt segment and the percent of total bolt volume. This percentage applied to total bolt weight gave the weight of the bolt segment from 4 inches d.o.b. to 2 inches d.o.b. Regression analysis was then used to estimate the weight of the piece above 4 inches d.o.b. and below 2 inches d.o.b., for each d.b.h. class. This amount subtracted from the estimated stem weight to 2 inches gave the stem weight to 4 inch d.o.b. for each class.

RESULTS

Regression equations were developed to estimate green and dry weight of the total above-stump tree weight, the stem weight to 2 inches d.o.b., and the top weight above 2 inches d.o.b. plus live and dead branches. The regression coefficients were calculated using the weight determined by field weighing.

The model used to fit individual tree weights is:

$$\log_{10} Y = a + b \log D$$

where: Y = the weight variable of interest
D = tree d.b.h. in inches
a and b are coefficients estimated from the data

Table 2 presents the estimates of the coefficients for predicting the variable of interest. Additional statistics presented are the coefficients, standard errors, t-statistics, the regression standard error of estimate, and the correlation coefficient.

The variance of the Y variable gets larger as d.b.h. increases; therefore, logarithmic transformations were made to satisfy the basic assumptions of the regression process for homogenity of variances (Ostle 1963).

Weight Estimates

Using individual tree d.b.h., we can estimate total tree weight, stem weight to 2 inches d.o.b., top and branch weight, weight of top and live branches, and dead branch weight.

The green and dry weights for the total tree and various tree components are shown in table 3. The crown (top plus limbs) weight above a 4-inch top, can be determined by calculating the difference between the two stem weights and adding it to the top and limb weight shown.

Seasonal Moisture Content

Stem moisture contents are presented for each week from August 22 to September 19, 1975, because a large number of trees were cut for total weight determination during that period (table 4). For the rest of the year, mid-month data are shown.

No consistent seasonal moisture content trend is indicated by the sample. The marked difference between the samples taken in July of 1975 and those taken in 1976 suggests a possible annual trend because the samples were selected from the same area. Stem heartwood moisture is the most consistent; bark and sapwood show the most variation.

Table 2.—*Regression statistics for predicting tamarack tree weight*[1]

	Constant			D.b.h.			Standard error of estimate	
Component	a	se	t	b	se	t		R^2
				GREEN WEIGHT (POUNDS)				
Total tree	0.6837	0.039	17.46	2.271	0.048	46.84	0.059	0.977
Stem to 2 inches	.4628	.047	9.91	2.364	.058	40.89	.070	.970
Top & branch	.3080	.095	3.23	2.040	.118	17.23	.143	.853
Live branches	.2600	.115	2.26	2.010	.143	13.98	.173	.793
Dead branches	.700	.187	3.78	2.250	.231	9.54	.280	.641
				DRY WEIGHT (POUNDS)				
Total tree	.4065	.039	10.45	2.298	.048	47.74	.058	.978
Stem to 2 inches	.1755	.053	3.33	2.393	.065	36.66	.079	.963
Top & branch	.0218	.091	.24	2.099	113	18.59	.137	.871
Live branches	.0646	.115	.56	2.055	.142	14.47	.172	.804
Dead branches	.700	.182	4.26	2.230	.226	9.78	.273	.652

[1] $\log_{10} Y = a + b \log D$.

Table 3.—*Estimated green and dry weights of tamarack trees and components by d.b.h.*

D.b.h. (inches)	Total tree	Stem to 2 inches	Top above 2 inches, plus limbs	Live limbs and top	Dead limbs	Stem to 4 inches
			GREEN WEIGHT (POUNDS)			
3	58	39	19	17	2	—
4	112	77	34	30	5	25
5	187	130	54	46	7	82
6	282	201	79	67	11	157
7	401	289	108	91	16	248
8	543	396	141	119	21	358
9	709	523	180	151	28	487
10	901	671	223	186	35	637
11	1,119	841	271	226	44	809
12	1,363	1,033	323	269	53	1,003
13	1,635	1,248	381	316	64	1,220
14	1,934	1,487	443	366	76	1,460
15	2,263	1,750	510	421	88	1,725
16	2,620	2,039	581	479	102	2,015
			DRY WEIGHT (POUNDS)			
3	32	21	11	8	2	
4	62	41	19	15	4	
5	103	70	31	24	7	
6	157	109	45	34	11	
7	223	158	62	47	15	
8	303	217	83	62	21	
9	398	288	106	79	27	
10	506	370	132	98	34	
11	630	465	161	119	42	
12	770	573	194	142	51	
13	925	694	229	168	61	
14	1,097	828	268	195	72	
15	1,286	977	309	225	84	
16	1,491	1,140	354	257	97	

Weather data registered at a nearby station showed that precipitation January through May 1976 was well below normal and much below the same period in 1975. This drought may have influenced the moisture content of the sample during this period.

We analyzed the change in moisture content of wood vertically in the tree by d.b.h. class using 53 trees in the August-September sample (table 5). Moisture content generally increased as height increased except for the stump to d.b.h. section.

Thirty-nine of the trees had odd length pieces above the top of the last full bolt; in 14 cases the 2-inch d.o.b. coincided with the top of a full bolt. In all but three trees, moisture content was higher at 2 inches d.o.b., and the difference ranged up to 50 percent higher even though often only 2 or 3 feet above the next lower measurement. This could be due in part to transpirational pull after felling and the timing of severing the top from the stem. Moisture is lowest in the lower sections, increases somewhat in the upper bolts, and is usually much higher at the 2-inch d.o.b. point. As a practical matter, however, it appears that moisture content is not radically different for the bulk of the stem volume.

Density and Specific Gravity

Average weighted stem specific gravity and oven-dry density as calculated from specific gravity are

Table 4.—*Average stem and stem component moisture content, July 1975 to July 1976, for tamarack in northern Minnesota*

Date	Weather condition	Trees	Total stem	Stem wood	Stem sap	Stem heart	Stem bark
1975		*Number*			*Percent*		
July 23-25	Wet	10	93.9	90.8	127.9	52.0	121.7
Aug. 22-28	Dry	13	85.1	83.8	102.9	52.2	99.2
Sept. 2-5	Dry	14	91.2	90.4	115.6	58.5	98.7
Sept. 8-12	Dry	15	80.6	79.7	109.0	51.4	90.3
Sept. 15-19	Dry	11	79.3	78.3	117.1	51.2	90.9
Oct. 14-15	Very dry	8	87.6	87.4	116.8	56.0	92.1
Nov. 24-26	Very wet	8	83.4	81.7	114.8	54.4	105.1
Dec. 15-17	Normal	8	82.5	79.3	124.8	51.3	126.6
1976							
Jan. 13,14,22	Very dry	8	87.0	84.9	117.4	53.8	112.9
Feb.17,19	Very dry	8	89.1	87.7	116.2	55.2	112.9
March 17-19	Very dry	8	82.6	80.8	129.8	51.2	104.5
April 14-16	Very dry	8	74.6	73.2	113.9	51.1	93.8
May 10-12	Very dry	8	87.8	87.8	117.5	55.7	89.7
June 21-23	Wet	8	77.0	75.5	102.9	51.0	93.1
July 19,21	Normal	8	83.5	82.7	111.2	54.2	91.2
Annual average		143	84.5	83.1	115.3	53.3	100.4
Standard deviation			9.5	9.9	13.9	7.4	14.8
Standard error/mean			0.8	0.8	1.2	0.6	1.2

Table 5.—*Moisture content of tamarack stemwood by d.b.h. class*[1] *and height in feet above stump*

D.b.h. (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number	*Percent*									
3	3	96.7	90.3	99.0	121[1]						127
4	7	77.6	77.3	78.9	90.2[6]	78.0[2]	99.0[1]				116
5	12	82.3	81.1	78.3	87.8	106.8[10]	104.0[2]				122
6	10	78.7	75.4	79.4	85.8	103.2	104.2[4]	141.5[2]			124
7	6	75.2	71.0	69.2	84.3	89.8	100.7	113.7[3]			124
8	2	72.0	81.0	69.5	79.0	86.5	92.0	134.0			134
9	3	80.3	71.3	69.0	70.3	77.3	86.7	94.3	125.3		125
10	3	103.0	88.0	89.3	84.0	91.7	91.3	103.5[2]	121.0[1]		119
11	3	78.7	71.0	83.0	78.7	82.0	89.7	101.7	120.5[2]		131
12	2	89.0	80.0	78.0	82.5	83.0	84.5	95.0	117.5	109.0[1]	132
13	1	108.0	73.0	76.0	80.0	83.0	78.0	80.0	84.0	102.0	138
14	1	73.0	75.0	79.0	72.0	85.0	76.0	79.0	90.0	95.0	120
Total	53	82.0	77.8	78.7	85.1	94.3	94.2	107.2	114.7	102.0	124

[1] Superscripts show number of disks represented in the cell if less than number of trees in the d.b.h. class.

shown in table 6. The green density as determined by field weight and Smalian volume is shown in table 7 and compared to density calculated from specific gravity and moisture content for the same trees.

The discrepancy between the densities determined by the two methods is difficult to explain. All measurements were carefully made by trained operators. Other researchers have also experienced a similar result although this phenomena has not been reported in the literature. Although there is concern about the accuracy of the Smalian formula for determining volume, the same volume is used in both cases. Perhaps further research is needed to document the prevalence of this phenomena in developing weight estimates for tree species and, to estimate the relative accuracy of each method.

The weight/volume determined density for the stem averaged 5.4 pounds per cubic foot of wood and bark higher than that calculated from specific gravity. For individual trees, the former density ranged from 48.96 to 62.61; the latter ranged from 43.96 to 58.99. The difference held quite constant across the entire diameter range. Average green density calculated from specific gravity for the 53 sample trees in the weight study was 50.8 pounds per cubic foot of wood and bark ($Sx = 3.6$, $S\bar{x} = 0.50$). For the weight/volume green density, the average was 56.2 pounds per cubic foot of wood and bark ($Sx = 3.7$, $S\bar{x} = 0.51$).

Trends in specific gravity by d.b.h. and height in tree are shown for each component, tables 8-10. In the smaller d.b.h. classes, specific gravity generally decreased as height increased except that sapwood increased between the stump and d.b.h.

Wood and Bark Ratios

The proportion of bark decreases from stump to d.b.h. and then increases as height increases (table 11). The bark proportion decreases as d.b.h. increases. Heartwood, as expected, decreases as height in tree increases (table 12). It also increases as d.b.h. gets larger except at the 2-inch d.o.b. point where the reverse is true. Above 7 inches d.b.h., in general, heartwood proportion is constant in the lower portion of the stem and sapwood proportions are a mirror image of heartwood (table 13). The number of samples above 11 inches d.b.h. in this study are limited, and the number of disks at the higher points in each d.b.h. class are reduced because not all trees were tall enough to reach a particular height.

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Table 6.—*Average weighted stem specific gravity and ovendry density by component and d.b.h.*

D.b.h. inches	Trees	Specific gravity					Dry density				
		Sap	Heart	Wood	Bark	Stem	Sap	Heart	Wood	Bark	Stem
	Number						-----------*Pounds/cubic foot*-----------				
3	9	0.481 *.009	0.500 .008	0.489 .010	0.301 .006	0.459 .009	30.0	31.2	30.5	18.8	28.6
4	23	.484 .007	.493 .006	.488 .006	.282 .007	.457 .006	30.2	30.8	30.5	17.6	28.5
5	20	.460 .006	.476 .007	.466 .005	.297 .007	.441 .005	28.7	29.7	29.1	18.5	27.5
6	19	.459 .008	.482 .008	.469 .007	.292 .007	.444 .006	28.6	30.1	29.3	18.2	27.7
7	17	.451 .006	.480 .008	.465 .006	.295 .007	.443 .005	28.1	30.0	29.0	18.4	27.6
8	20	.440 .006	.463 .006	.452 .005	.294 .005	.432 .004	27.5	28.9	28.2	18.4	27.0
9	11	.452 .009	.489 .013	.470 .010	.301 .010	.448 .008	28.2	30.5	29.3	18.8	28.0
10	13	.434 .007	.463 .007	.449 .006	.301 .008	.430 .005	27.1	28.9	28.0	18.8	26.8
11	5	.422 .015	.447 .008	.436 .009	.288 .011	.417 .008	26.3	27.9	27.2	18.0	26.0
12	4	.390 .010	.430 .003	.412 .005	.299 .014	.399 .007	24.3	26.8	25.7	18.7	24.9
13	1	.421 —	.453 —	.438 —	.328 —	.427 —	26.3	28.3	27.3	20.5	26.6
14	1	.431 —	.448 —	.440 —	.314 —	.424 —	26.9	28.0	27.5	19.6	26.5
Total/Average	143	.455 .003	.477 .003	.465 .002	.294 .002	.441 .002	28.4	29.8	29.0	18.4	27.5

*Standard deviation

Table 7.—*Comparison of average weighted green density calculated from specific gravity and from green weight and volume*

D.b.h. (inches)	Trees	Green density from specific gravity	Green density from weighing	Ratio
	Number	*----Pounds/cubic foot----*		
3	3	54.6	60.2	0.906
4	7	51.9	57.2	.908
5	12	52.4	57.6	.909
6	10	51.4	57.1	.900
7	6	50.3	56.3	.893
8	2	47.9	55.8	.857
9	3	49.2	53.0	.928
10	3	51.4	53.1	.962
11	3	47.4	51.6	.919
12	2	46.3	51.6	.898
13	1	48.6	52.6	.923
14	1	47.6	51.9	.918
Average		50.8	56.2	
Sx		3.6	3.7	
Sx		0.50	0.51	

Table 8.—*Average weighted specific gravity of bark by d.b.h. and height (in feet) in tree*

D.b.h. (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number										
3	9	0.326	0.299	0.291	0.296						0.286
4	23	.307	.290	.284	.277	0.262	0.275				.278
5	20	.321	.307	.299	.296	.291	.280				.277
6	19	.324	.301	.290	.289	.279	.277				.279
7	17	.338	.300	.294	.285	.284	.287	0.273	0.263		.285
8	20	.321	.318	.294	.279	.293	.288	.284	.267		.275
9	11	.335	.309	.299	.302	.292	.300	.298	.290	0.340	.288
10	13	.337	.314	.298	.288	.302	.291	.296	.281		.283
11	5	.324	.292	.283	.281	.278	.275	.286	.273		.278
12	2	.383	.321	.297	.281	.310	.303	.302	.319	.293	.303
13	1	.370	.341	.316	.314	.308	.332	.332	.330	.349	.310
14	1	.352	.333	.306	.304	.309	.318	.314	.290	.317	.334

Table 9.—*Average weighted specific gravity of heartwood by d.b.h. and height (in feet) in tree*

D.b.h. (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number										
3	9	0.549	0.507	0.494	0.458						0.501
4	23	.542	.510	.494	.445	0.413	0.449				.632
5	20	.500	.482	.469	.463	.447	.458				.432
6	19	.517	.484	.476	.467	.454	.451				.449
7	17	.517	.481	.483	.463	.454	.471	0.467	0.496		.469
8	20	.492	.475	.463	.448	.442	.448	.455	.458		.455
9	11	.523	.508	.479	.477	.464	.469	.465	.474	0.515	.485
10	13	.465	.472	.463	.461	.446	.459	.462	.444		.461
11	5	.452	.438	.447	.455	.429	.438	.426	.445		.426
12	2	.441	.442	.428	.429	.424	.428	.451	.453	.557	.427
13	1	.466	.467	.446	.422	.450	.458	.518	.426	.457	.526
14	1	.435	.452	.450	.450	.438	.442	.479	.443	.524	.529

Table 10.—*Average weighted specific gravity of sapwood by d.b.h. and height (in feet) in tree*

D.b.h. (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number										
3	9	0.496	0.501	0.485	0.446						0.439
4	23	.507	.527	.500	.469	0.443	0.457				.437
5	20	.465	.485	.470	.455	.437	.441				.421
6	19	.472	.480	.470	.463	.445	.437				.431
7	17	.452	.480	.469	.445	.436	.446	0.420	0.419		.426
8	20	.450	.462	.452	.438	.438	.431	.422	.382		.415
9	11	.440	.462	.450	.456	.445	.456	.456	.453	0.464	.429
10	13	.408	.443	.441	.434	.430	.455	.440	.403		.437
11	5	.407	.417	.423	.446	.420	.432	.432	.426		.414
12	2	.402	.432	.388	.389	.391	. 413	.415	.434	.420	.404
13	1	.409	.445	.433	.418	.420	.403	.428	.414	.422	.413
14	1	.379	.423	.458	.411	.428	.409	.477	.492	.499	.466

Table 11.—*Weighted average bark percent of green disk weight by d.b.h. and height (in feet) in tree*

D.b.h (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number	*Percent*									
3	9	12	10	11	[1]13^{6}						15
4	23	11	8	9	10^{22}	12^{12}	14^{3}				15
5	20	10	8	9	10	13^{19}	13^{5}				16
6	19	10	8	8	10	12	13^{9}				18
7	17	9	7	8	8	10	12	14^{10}	16^{1}		17
8	20	9	7	7	8	10	11	14^{17}	17^{1}		18
9	11	8	7	7	8	10	11	12	15^{6}	19^{1}	18
10	13	9	7	7	8	9	11	13^{11}	16^{4}		17
11	5	8	8	8	8	9	11	13	15^{2}		18
12	2	8	8	7	9	9	12	11	15	17^{1}	19
13	1	10	6	6	6	8	9	11	14	17	24
14	1	7	8	7	7	9	8	12	17	17	23

[1] Superscripts show the number of disks involved when less than the number of trees.

Table 12.—*Weighted average heartwood percent of green disk weight by d.b.h. and height (in feet) in tree*

D.b.h (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number	*Percent*									
3	9	40	32	22							19
4	23	44	47	42	34	28	12				17
5	20	45	45	40	31	21	18				10
6	19	43	45	40	34	24	17				9
7	17	50	51	49	39	32	23	14	8		7
8	20	52	50	50	42	33	24	14	8		8
9	11	52	53	50	43	36	27	18	11	7	6
10	13	49	52	48	42	33	26	18	10		8
11	5	50	50	44	41	33	24	14	15		5
12	2	50	53	51	43	39	32	25	18	7	3
13	1	35	58	52	53	46	44	34	24	13	6
14	1	59	57	52	55	40	44	28	15	3	1

Table 13.—*Weighted average sapwood percent of green disk weight by d.b.h. and height (in feet) in tree*

D.b.h (inches)	Trees	Height above stump									At 2 inches d.o.b.
		0	4	8	16	24	32	40	48	56	
	Number	*Percent*									
3	9	48	49	57	65						66
4	23	45	45	49	56	60	74				68
5	20	45	47	51	59	66	70				74
6	19	47	47	51	56	64	70				72
7	17	41	42	44	52	58	65	72	76		76
8	20	39	43	43	50	57	65	72	75		74
9	11	40	40	43	49	54	62	70	74	74	76
10	13	42	41	45	50	58	63	69	74		75
11	5	42	42	48	51	58	65	73	70		77
12	2	42	39	42	48	52	56	64	67	76	78
13	1	55	36	42	41	46	48	55	62	70	70
14	1	34	35	41	38	51	48	60	68	80	75

Carpenter, Eugene M.
Above-ground weights for tamarack in northeastern Minnesota.
Res. Pap. NC-245. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 9 p.

We used trees from natural, uneven-aged stands in northeastern Minnesota to develop prediction equations to estimate total tree, stem, crown, live and dead branch weight. Presented here are specific gravity and moisture content by d.b.h. and height in tree, as well as bark, sapwood, and heartwood ratios.

KEY WORDS: Tamarack biomass, *Larix laricina* [Du Roi] K., equations, weight, component proportions, specific gravity trends, moisture content trends.

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